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DESIGN INFORMATION ON AM-350 STAINLESS STEEL FOR AIRCRAFT AND MISSILES

DEFENSE METALS INFORMATION CENTER
Battelle Memorial Institute
Columbus 1, Ohio

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by

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to

OFFICE OF THE DIRECTOR OF DEFENSE
RESEARCH AND ENGINEERING

DEFENSE METALS INFORMATION CENTER
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ACKNOWLEDGMENTS

The authors wish to thank Mr. D. A. Shinn, Air Force Member, Federal Aircraft Design Criteria Committee, Structures Subcommittee (formerly the ANC-5 Panel), for permission to publish the design curves generated on Air Force Contract No. AF 33(616)-6410.

Most of the detailed information on specific alloys has come from material producers and published papers by producers, fabricators, and users of these alloys. References on this information are included in the bibliography.

TABLE OF CONTENTS

DESIGN INFORMATION ON AM-350 STAINLESS STEEL FOR AIRCRAFT AND MISSILES

SUMMARY

The information contained in Appendixes A and B to this report was presented at the Los Angeles meeting of the Structures Subcommittee (formerly ANC-5 Panel) of the Federal Aircraft Design Criteria Committee, November 15, 16, and 17, 1960.

Tentative room-temperature design-allowable strengths and elevated-temperature design curves for short-time ultimate tensile strength, tensile yield strength, compressive yield strength, ultimate shear strength, bearing ultimate strength, and bearing yield strength are presented. These curves are based on a number of published and unpublished reports and papers. Data are summarized in Appendix A in the format recommended for MIL-HDBK-5 (superseding ANC-5), Strength of Metal Aircraft Elements. Appendix B contains summary plots of substantiating data from which design-allowable strengths were derived.

GENERAL COMMENTS

AM-350 is one of the semiaustenitic precipitation-hardenable stainless steels. In the annealed condition it is soft and ductile and has many of the desirable forming characteristics of the austenitic stainless steels. When hardened, it is strong and hard like the martensitic stainless steels.

The primary application for AM-350 is for parts and assemblies requiring high strength and oxidation resistance up to 800 F. It is available in sheet, strip, foil, welded tubing, billets, bars, forgings, and wire.

The AM-350 analysis is covered by the AMS and MIL specifications listed on page A-3, Appendix A.

MANUFACTURING CONSIDERATIONS

Heat Treatment and Forming

In the annealed condition AM-350 is essentially austenitic (approximately 5 to 15 per cent delta ferrite) and has forming characteristics similar to the AISI 300 series stainless steels. However, it does have a higher rate of strain hardening. Hardened AM-350 is martensitic, but does retain sufficient ductility to permit limited forming or straightening operations.

Condition H (see Table 1) is the most suitable for forming complex parts, and AM-350 is normally shipped from the mill in this condition. Cold forming with Condition H material will cause hardening by martensite formation in addition to strain hardening in proportion to the amount of deformation. Hardening can be minimized by working at 300 F or above.

AM-350 can be fully hardened from Condition H by the double-aging (DA) heat treatment which is accomplished by first aging at about 1375 F and then at about 850 F. The 1375 F age precipitates chromium carbides from the austenitic matrix and alters the composition of the austenite so that the austenite transforms to martensite on cooling to room temperature. The second age at 850 F tempers the martensite.

Another method of hardening AM-350 is by subzero cooling and tempering (SCT). AM-350 in Condition H responds only partially to the subzero cooling so that it is necessary to reanneal to Condition L (described in Table 1) before subzero cooling and tempering. Sufficient ductility is retained after the SCT treatment to allow limited forming operations. For example, AM-350 (SCT) sheet or strip can be bent 180 degrees over a 3T pin.

The designer should be aware that a dimensional growth of about 0.004 to 0.005 in./in. occurs when AM-350 is hardened.

A detailed discussion of heat treatment and the interaction of fabricating and heat-treating variables is presented in DMIC Report 111, "The Physical Metallurgy of Precipitation-Hardenable Stainless Steels", by Ludwigson and Hall.

TABLE 1. CONDITIONS AND HEAT TREATMENTS OF AM-350

Condition	Heat Treatment	Purpose
H	Solution treated at 1850 to 1975 F, air cooled or water quenched	Formability
L	Solution treated at 1710 F ±25, air cooled or water quenched	Preparation for hardening
DA	Condition L or Condition H, plus 3 hours at 1375 F ±25, air cooled to 80 F max., plus 3 hours at 850 F ±25, air cooled	Hardening
SCT	Condition L plus 3 hours at -100 F plus 3 hours at 850 to 1000 F, air cooled	Hardening

Forging

AM-350 is readily forged. Forging temperatures above 2150 F should be avoided because of the free ferrite which may be formed. Free ferrite will decrease heat-treating response.

Finishing temperatures should be in the range of 1700 to 1800 F to prevent grain coarsening on subsequent solution treatment and to promote homogeneous precipitation of carbides. For optimum properties, a conditioning treatment after forging is recommended.

Welding

AM-350 can be welded by all of the conventional methods used for the chromium-nickel stainless steels. As-welded AM-350 can be hardened by the DA treatment without reannealing. For optimum properties, however, postweld reannealing is recommended.

To obtain proper response to the SCT treatment after welding, the alloy must be reannealed at 1710 F ±25 prior to hardening.

For a detailed discussion on the welding of AM-350, DMIC Report 118, "Welding of High-Strength Steels for Aircraft and Missile Applications", by Mishler, Monroe, and Rieppel, is recommended.

Machining

AM-350 has a very high rate of work hardening as well as a tendency to be soft and gummy in the annealed condition. For best machinability, AM-350 should be in the equalized and overtempered condition. This condition is produced by heating to 1425 F, cooling to room temperature, and overtempering at 1000 to 1100 F. This gives a hardness of approximately Rockwell C35, and the alloy then machines like low-alloy steels of similar hardness. Finishing operations may be performed in this condition if proper allowances are made for growth which occurs upon reannealing and hardening. If extreme dimensional accuracy is required, finish machining should be done in the hardened condition. Machining recommendations as reported by Metcut Research Associates are presented in Table 2.

Thermal machining of AM-350 is currently under development. Nelson, Scott, and Gassner[19] report that face-milling tests on induction-heated AM-350 (Bhn 380 or about Rockwell C41) have shown tool life at 1000 F to be about 100 times normal. On the other hand, turning tests on AM-350 (Bhn 400) at various temperatures up to 900 F have shown only a five-time improvement in tool life.

Corrosion Resistance

AM-350 shows good corrosion-resisting properties in ordinary atmospheres and also in a number of chemical environments. However, different corrosion behavior results from the two hardening treatments, SCT and DA. The greater precipitation of chromium carbides during the DA treatment causes some susceptibility to intergranular corrosion. For this reason, DA is less desirable than SCT where exposure to certain severe environments is expected.

A literature survey and limited investigation on the susceptibility of AM-350 to stress corrosion is reported in WADD Technical Note 60-95, "Stress Corrosion of Notched and Unnotched AM-350 Alloy", by Ault. Ault concluded that "stress-raisers such as mechanically induced notches do not have an appreciable effect on the susceptibility of the alloy to stress corrosion cracking. Rather the more important factor is local surface defects or inhomogeneities in the material. It was also found that concentration cell corrosion may be an important consideration for AM-350."

TABLE 2. MACHINING AM-350, SOLUTION TREATED AND AGED TO BHN 444[22]

Operation	Tool Material	Tool Geometry[a]	Tool Used for Tests	Depth of Cut, in.	Width of Cut, in.	Feed	Cutting Speed, ft/min	Tool Life	Wear-Land,[b] in.	Cutting Fluid
Turning	C-2 carbide	SR: 5°; SCEA: 15°; BR: 0°; ECEA: 15°; Relief: 5°	1/2-in.-square throwaway holder with mechanical chip breaker	0.100	--	0.009 in./rev.	150	40+ min.	(c)	None
Turning	Stellite 98 M-2 cast alloy	SR: 15°; SCEA: 0°; BR: 0°; ECEA: 5°; Relief: 5°	5/8-in.-square tool bit	0.060	--	0.009 in./rev.	70	80 min.	0.060	Soluble oil (20:1)
Turning	T-15 HSS	SR: 15°; SCEA: 0° BR: 0°; ECEA: 5°; Relief	5/8-in.-square tool bit	0.060	--	0.009 in./rev.	40	75 min.	0.060	Soluble oil (20:1)
Face milling	C-2 carbide	AR: 0°; ECEA: 5°; RR: 0°; CI: 8°; CA: 45°	5-in.-diam., 5-tooth, inserted-tooth face mill	0.100	2	0.005 in./tooth	120	37 in./tooth	0.012	None
Face milling	T-15 HSS	AR: 0°; ECEA: 5°; RR: 0°; CI: 8°; CA: 45°	4-in.-diam., single-tooth face mill	0.060	2	0.010 in./tooth	60	70 in./tooth	0.030 localized wear	Soluble oil (20:1)
Side milling Down-milling setup	C-2 carbide	AR: 0°; ECEA: 5°; RR: -15°; CI: 8°; CA: 45°	7-in.-diam., 6-tooth inserted-tooth face mill	0.100	1-3/4	0.010 in./tooth	120	50 in./tooth	0.016	None
Slot milling Down milling setup	C-1 or C-2 carbide	AR: 5° binegative; RR: -5°; ECEA: 1°; CA: 45° X 0.030 in.; CI: 8°	6-in.-diam., brazed 6-tooth slotting cutter	0.250	1	0.003 in./tooth	125	63 in./tooth	0.016	None

TABLE 2. (Continued)

Operation	Tool Material	Tool Geometry[a]	Tool Used for Tests	Depth of Cut, in.	Width of Cut, in.	Feed	Cutting Speed, ft/min	Tool Life	Wear-Land,[b] in.	Cutting Fluid
End milling	T-15 HSS	35° RH helix; CA: 45° X 0.060 in.; Per. Cl: 15°	3/4-in.-diam., 4-flute end mill[d]	0.250	3/4	0.002 in./tooth	70	150 in.	0.008	Soluble oil (20:1)
Drilling	T-15 HSS	2-flute, 118° crankshaft point; 7° clearance	1/4-in.-diam. drill, 2-1/2 in. long[e]	0.500 through hole	--	0.005 in./rev.	20	107 holes	0.016	Highly sulphurized oil + light machine oil (1:1)
Tapping	M-10 HSS	4-flute taper tap; 75% thread	5/16-18 NC taper tap	0.500 through hole	--	--	5	200+ holes	(f)	Highly chlorinated oil

(a) AR = axial rake; RR = radial rake; CA = corner angle; SR = side rake; BR = back rake; SCEA = side-cutting edge angle; ECEA = end-cutting edge angle; Cl = clearance.

(b) Wear on the peripheral flank of the cutter.

(c) Test stopped at 40-min tool life; 0.005-in. wear-land.

(d) For end mills 1/2-in. diam. and over. Flute length should be short as possible for maximum rigidity.

(e) Use stub-length drills whenever possible.

(f) Test discontinued, tap still cutting.

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(16) Allegheny Ludlum Data Sheet 125-71659-350, "Shear and Bearing Strength of AM-350 at Room and Elevated Temperatures".

(17) Allegheny Ludlum Data Sheet 86-111457-350, "Room and Elevated Temperature Tensile and Compressive Properties of Type AM-350".

(18) Allegheny Ludlum Memorandum, "AM-350 and AM-355 Cleaning".

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APPENDIX A

PROPOSED DESIGN-ALLOWABLE STRENGTHS FOR MIL-HDBK-5

Presented at the 20th meeting of the ANC-5 Panel on "Strength of Metal Aircraft Elements", held in Los Angeles, November 15, 16, and 17, 1960. These data, subject to approval by the Panel, will constitute a revision to MIL-HDBK-5, dated March, 1959.

APPENDIX A

PROPOSED DESIGN-ALLOWABLE STRENGTHS FOR MIL-HDBK-5

Introduction

Design-allowable strengths for AM-350 stainless steel products in various conditions have been proposed for amending the March, 1959, issue of MIL-HDBK-5, Strength of Metal Aircraft Elements. When approved, these data will provide guidance to designers concerned with airframe and missile structures.

The following glossary of terms is supplied for those readers not familiar with MIL-HDBK-5:

F_{tu} — Guaranteed minimum room-temperature ultimate tensile strength

UTS — Typical or average ultimate tensile strength

F_{ty} — Guaranteed minimum room-temperature yield strength at 0.2% offset

TYS — Typical or average tensile yield strength

F_{cy} — Minimum yield strength in compression at 0.2% offset

CYS — Typical or average compressive yield strength

F_{su} — Minimum ultimate shear strength (may be pin shear, punch shear, or panel shear; refer to MIL-HDBK-5)

USS — Typical or average ultimate shear strength

F_{bru} — Minimum ultimate strength in bearing at a specified e/D ratio

UBS — Typical or average ultimate bearing strength

F_{bry} — Minimum yield strength in bearing at a specified e/D ratio and a specified hole elongation value

BYS — Typical or average bearing yield strength

L — Longitudinal

T — Transverse

e/D — Ratio of edge distance to diameter of pin or fastener hole used to determine bearing strength

e, — Per cent elongation in uniaxial tension, usually in 2 inches

E — Modulus of elasticity in tension

E_c — Modulus of elasticity in compression

G — Modulus of rigidity

ω — Density

C — Specific heat

K — Thermal conductivity

α — Coefficient of thermal expansion, mean.

Additional definitions and nomenclature and derived relationships will be found in MIL-HDBK-5.

ITEM 60-14. ATTACHMENT TO THE MINUTES OF THE ANC-5 PANEL MEETING

Subject: Tentative Design Data on AM-350 Stainless Steel

2.2.4 AM-350 Stainless Steel

2.2.4.0 Specifications, Comments, and Room-Temperature Properties

Specifications. Material specifications for AM-350 stainless steel are presented in Table 2.2.4.0(a).

TABLE 2.2.4.0(a). MATERIAL SPECIFICATIONS FOR AM-350 STAINLESS STEEL

Alloy and Condition	Specification	Type of Product
AM-350	MIL-S-8840	Sheet and strip
AM-350	AMS 5554	Tubing, seamless
AM-350 (equalized and overtempered)	AMS 5745	Bars, forgings, and forging stock

Comments. The primary application of AM-350 is for parts requiring high strength and oxidation resistance up to 800 F. AM-350 is readily forged, welded, and brazed. The designer should be aware that after a forming operation, it is usually necessary to reanneal AM-350 before the alloy can be hardened and also that a dimensional growth of approximately 0.004 to 0.005 in./in. occurs during the hardening treatment. AM-350 can be hardened by subzero cooling and tempering (Condition SCT) or by double aging (Condition DA). The properties in the SCT condition are higher than those reported for the DA condition, but if the SCT method of hardening is selected it is necessary to precede it with a 1710 F annealing treatment in cases where the material was previously annealed at 1850 to 1975 F (Condition H as supplied by the mill).

Room-Temperature Properties. The room-temperature properties of AM-350 in the double-aged (DA) and in the subzero cooled and tempered (SCT) conditions are shown in Table 2.2.4.0(b). The ultimate tensile strength, tensile yield strength, and elongation values are taken from the material specifications. Other properties are derived from test data.

The elevated-temperature properties of AM-350 are presented in the following sections:

Section	Material Condition
2.2.4.1	DA
2.2.4.2	SCT

TABLE 2.2.4.0(b) DESIGN MECHANICAL AND PHYSICAL PROPERTIES OF AM-350 STAINLESS STEEL

Alloy	AM-350	
Form	Sheet, strip, bars, forgings, and seamless tubing	Sheet, strip, bars, and forgings
Condition	DA	SCT
Basis	Minimum specification values and typical values adjusted to minimum	
Mechanical Properties		
F_{tu}, ksi	165	185
F_{ty}, ksi	135	150
F_{cy}, ksi	148	170
F_{su}, ksi	112	123
F_{bru}, ksi		
(e/D = 1.5)	260	295
(e/D = 2.0)	345	372
F_{bry}, ksi		
(e/D = 1.5)	198	230
(e/D = 2.0)	230	260
e, per cent	10[(a)]	10[(a)]
E, 10^6 psi	30.0	
E_c, 10^6 psi	--	
G, 10^6 psi	11.3	
Physical Properties		
ω, lb/in.^{3}	Condition H 0.286 Condition SCT 0.282	
C, Btu/(lb)(F)	0.12 (32 to 212 F)	
K, Btu/[(hr)(ft^2)(F)/ft]	8.4 (at 100 F); 11.7 (at 800 F)	
α, 10^{-6} in./in./F	6.3(70 to 212 F); 7.2(70 to 932 F)	

(a) Per cent in 2 inches for sheet, strip, and tubing; per cent in 4D for bars and forgings.

2.2.4.1 Double-Aged Condition (DA)

The double-aged condition is developed in AM-350 by starting with the solution-treated condition (either Condition L or Condition H), aging at 1375 F for 3 hours, air cooling to room temperature, and then a second aging at 850 F for 3 hours and air cooling to room temperature.

Elevated-temperature data for the double-aged material are presented in Figures 2.2.4.1.1(a) through 2.2.4.1.6(b).

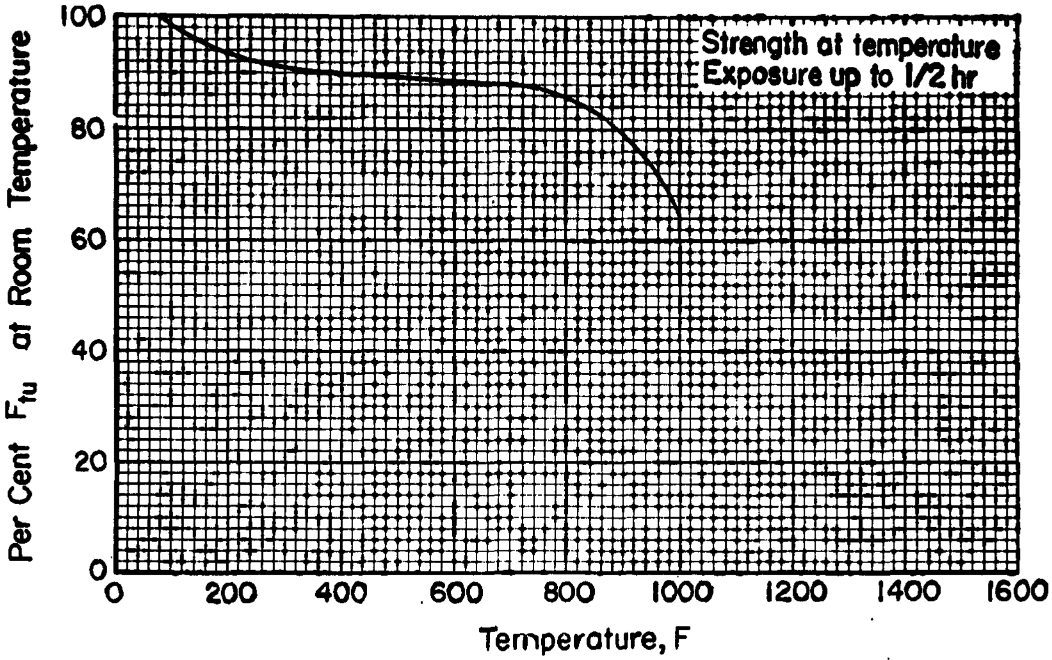

Figure 2.2.4.1.1(a). Effect of temperature on the ultimate tensile strength (F_{tu}) of AM-350 stainless steel (double-aged).

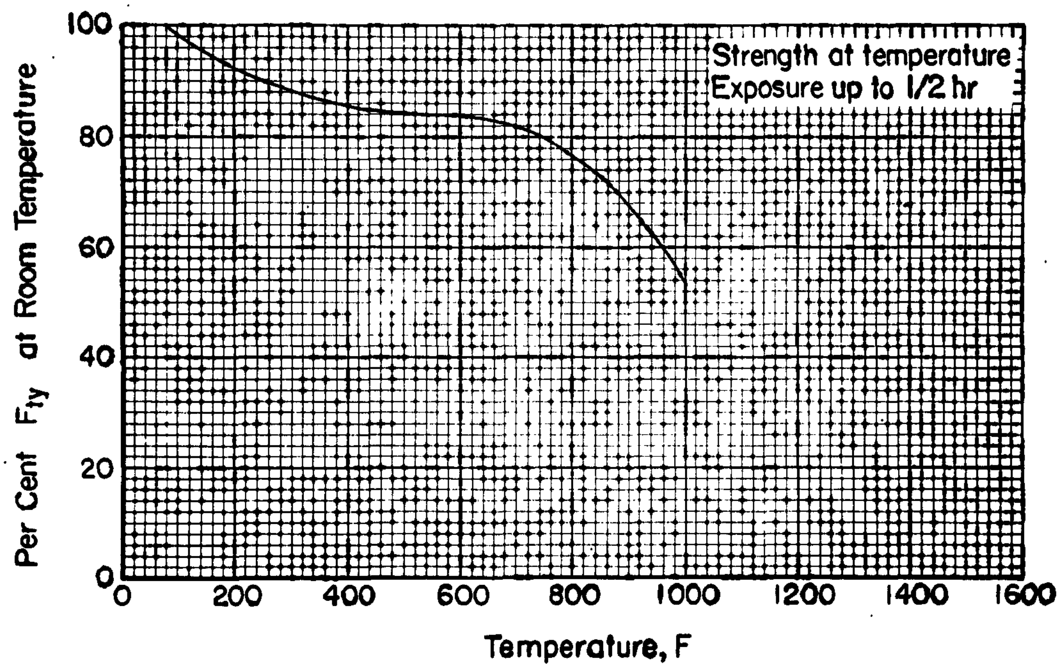

Figure 2.2.4.1.1(b). Effect of temperature on the tensile yield strength (F_{ty}) of AM-350 stainless steel (double-aged).

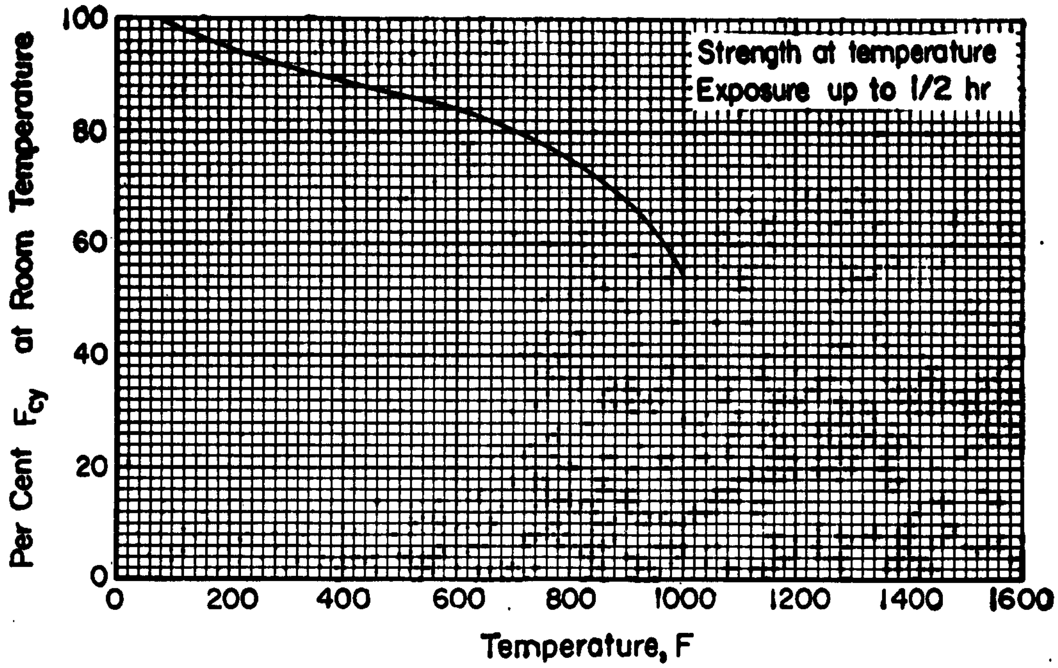

Figure 2.2.4.1.2(a). Effect of temperature on the compressive yield strength (F_{cy}) of AM-350 stainless steel (double-aged).

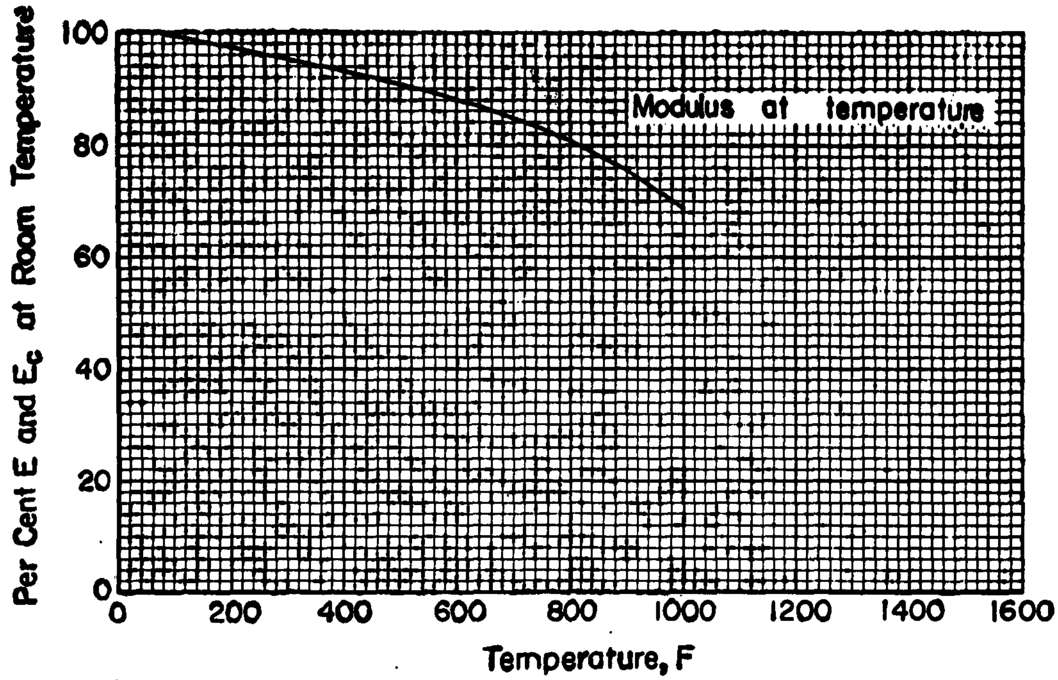

Figure 2.2.4.1.4. Effect of temperature on the tensile and compressive modulus (E and E_c) of AM-350 stainless steel (double-aged).

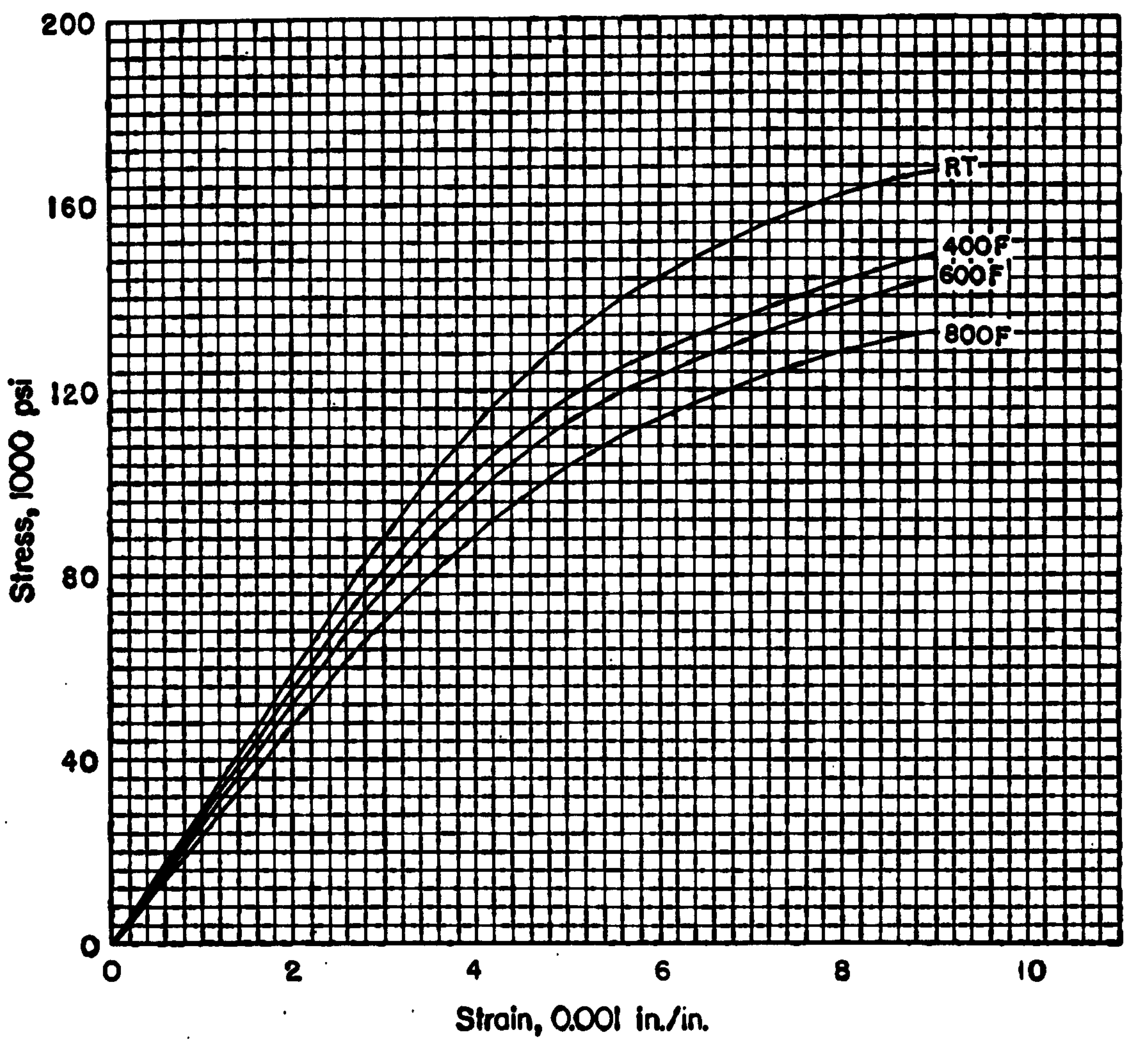

Figure 2.2.4.1.6(a). Typical tensile stress-strain curves for AM-350 stainless steel (double-aged) at room and elevated temperatures.

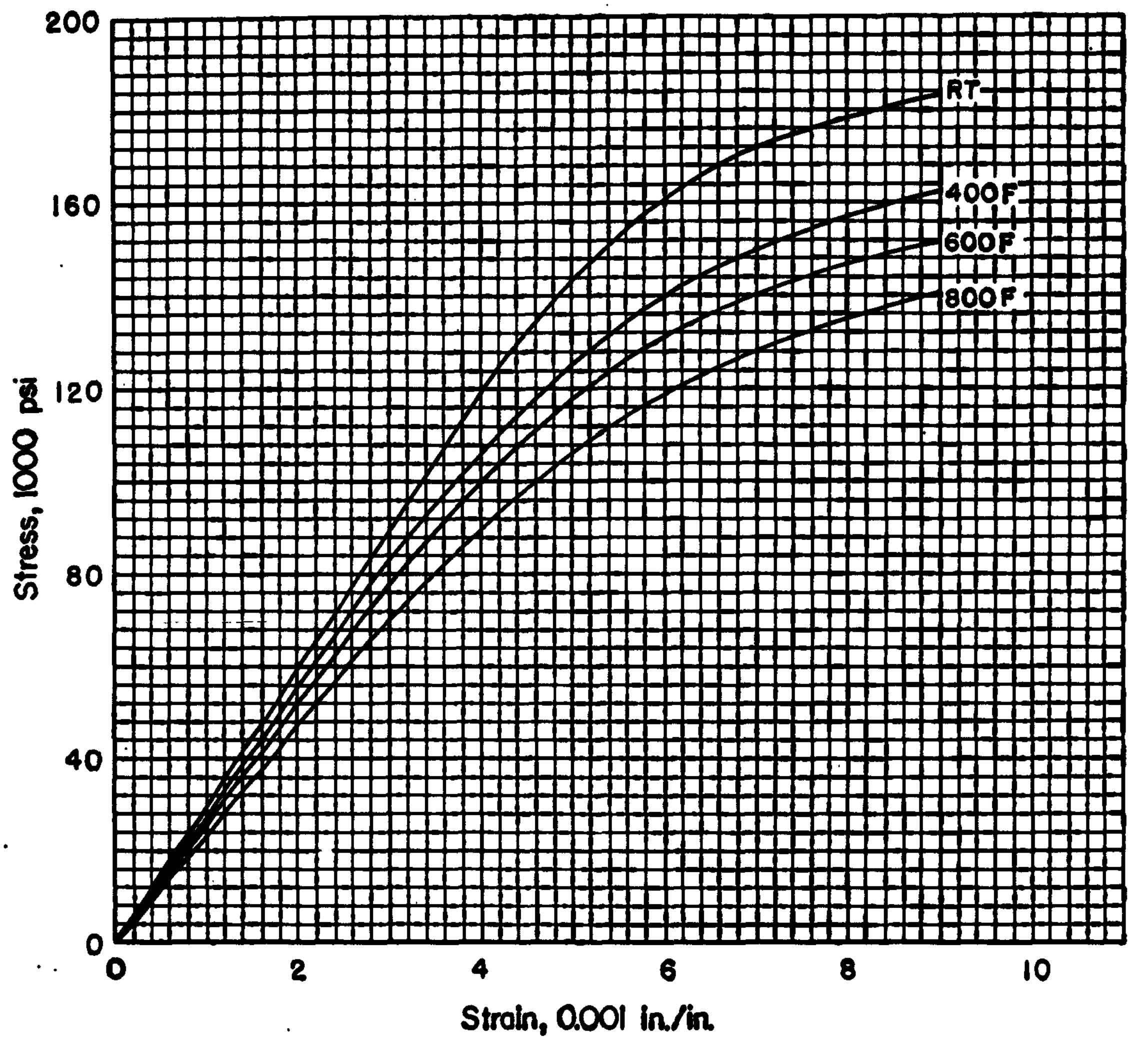

Figure 2.2.4.1.6(b). Typical compressive stress-strain curves for AM-350 stainless steel (double-aged) at room and elevated temperatures.

6.2.4.2 Subzero-Cooled and Tempered Condition (SCT)

The SCT condition is developed in AM-350 by starting with a solution treatment at 1710 F (Condition L) and then subcritically transforming at -100 F followed by aging at 850 to 1000 F.

Elevated-temperature data for the SCT material are presented in Figures 2.2.4.2.1(a) through 2.2.4.2.6(b).

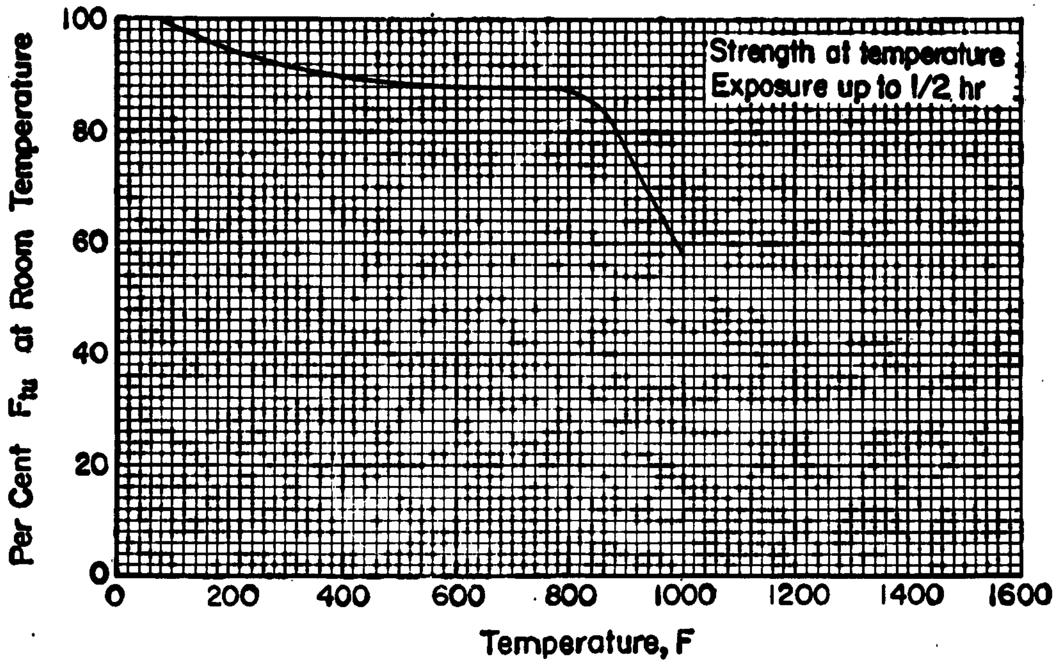

Figure 2.2.4.2.1(a). Effect of temperature on the ultimate tensile strength (F_{tu}) of AM-350 stainless steel (SCT).

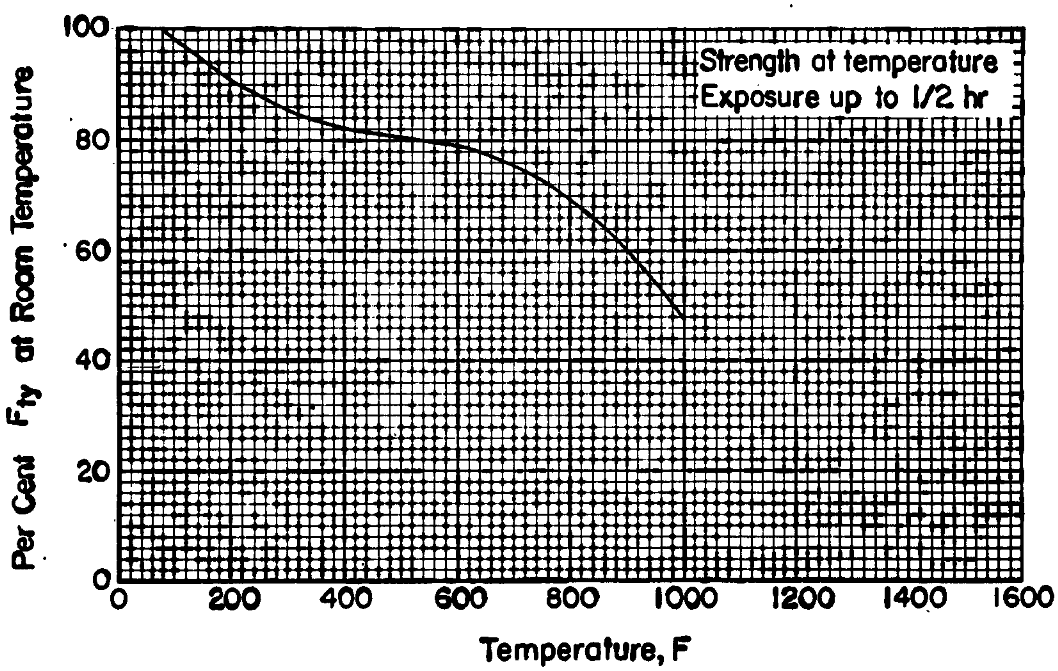

Figure 2.2.4.2.1(b). Effect of temperature on the tensile yield strength (F_{ty}) of AM-350 stainless steel (SCT).

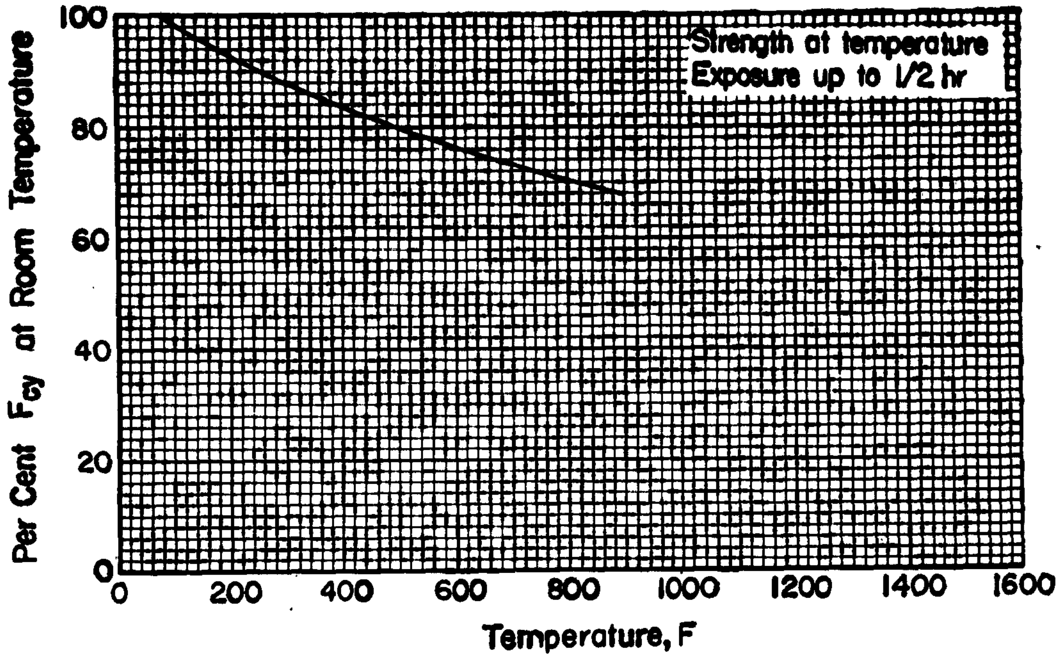

Figure 2.2.4.2.2(a). Effect of temperature on the compressive yield strength (F_{cy}) of AM-350 stainless steel (SCT).

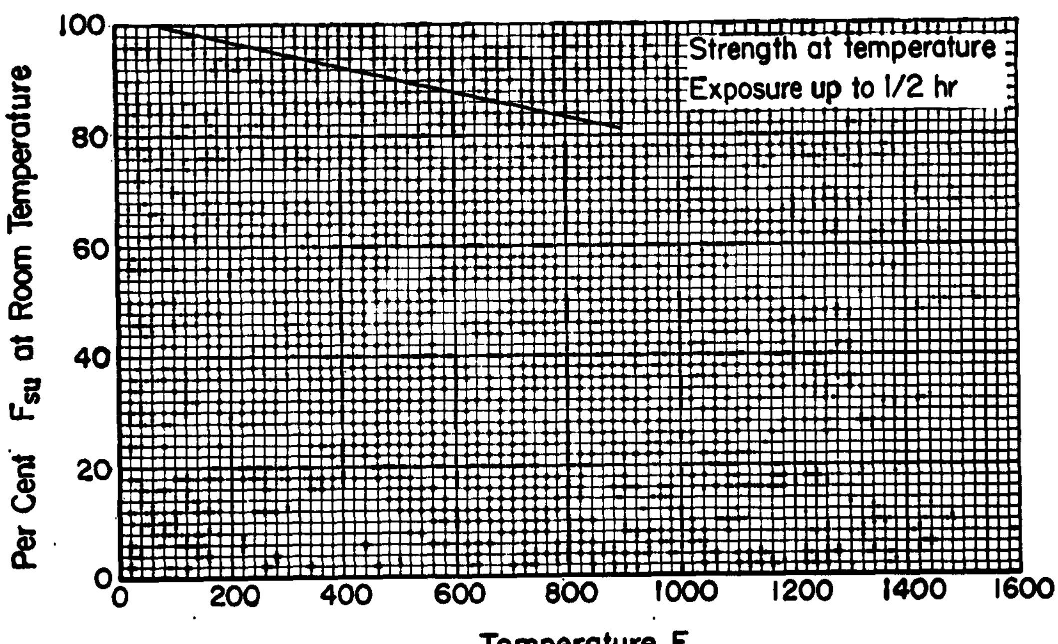

Figure 2.2.4.2.2(b). Effect of temperature on the ultimate shear strength (F_{su}) of AM-350 stainless steel (SCT).

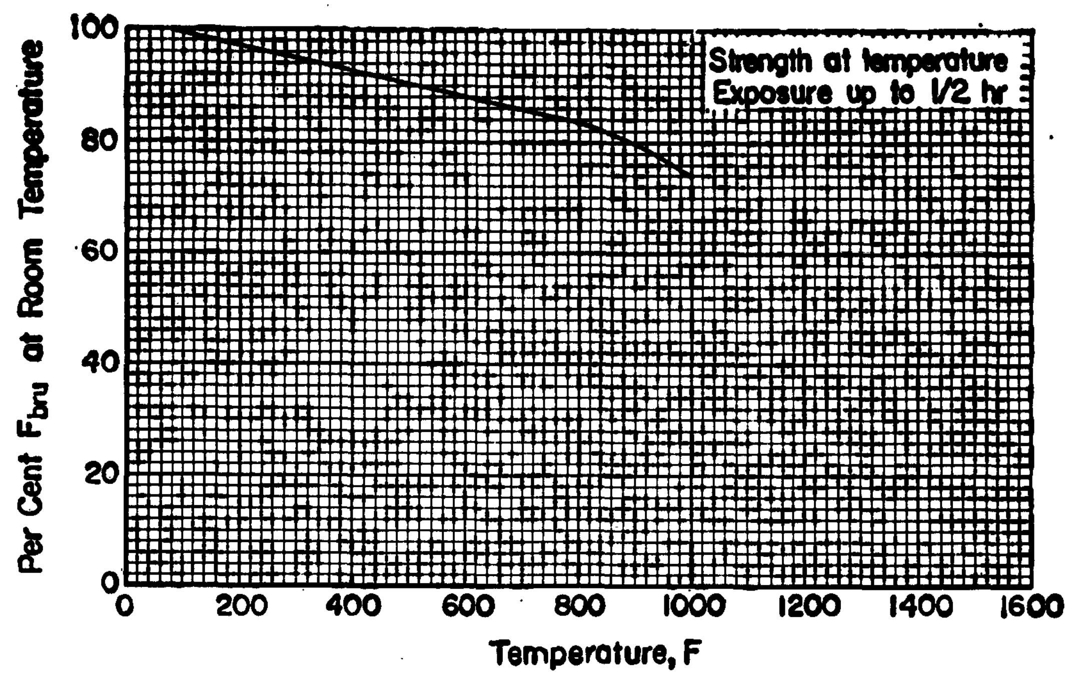

Figure 2.2.4.2.3(a). Effect of temperature on the ultimate bearing strength (F_{bru}) of AM-350 stainless steel (SCT).

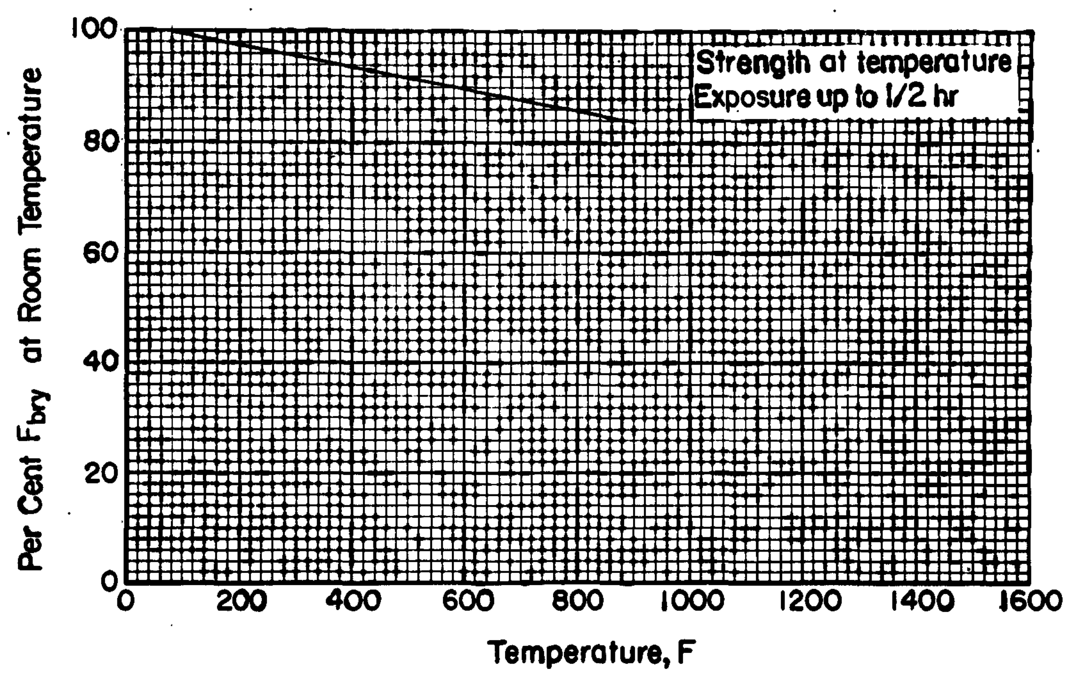

Figure 2.2.4.2.3(b). Effect of temperature on the bearing yield strength (F_{bry}) of AM-350 stainless steel (SCT).

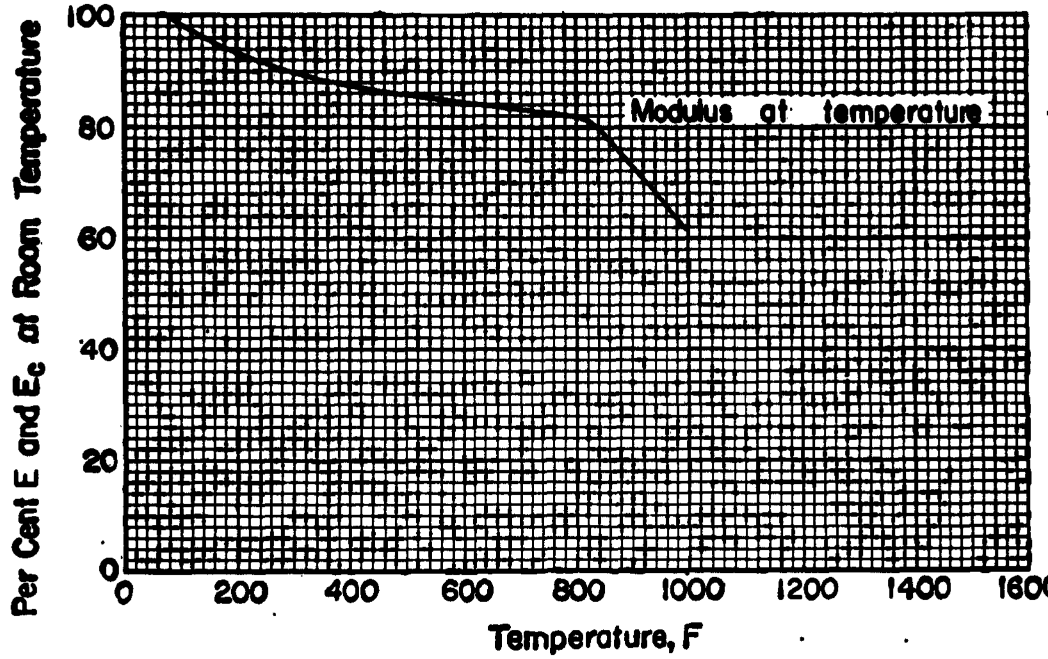

Figure 2.2.4.2.4. Effect of temperature on the tensile and compressive modulus (E and E_c) of AM-350 stainless steel (SCT).

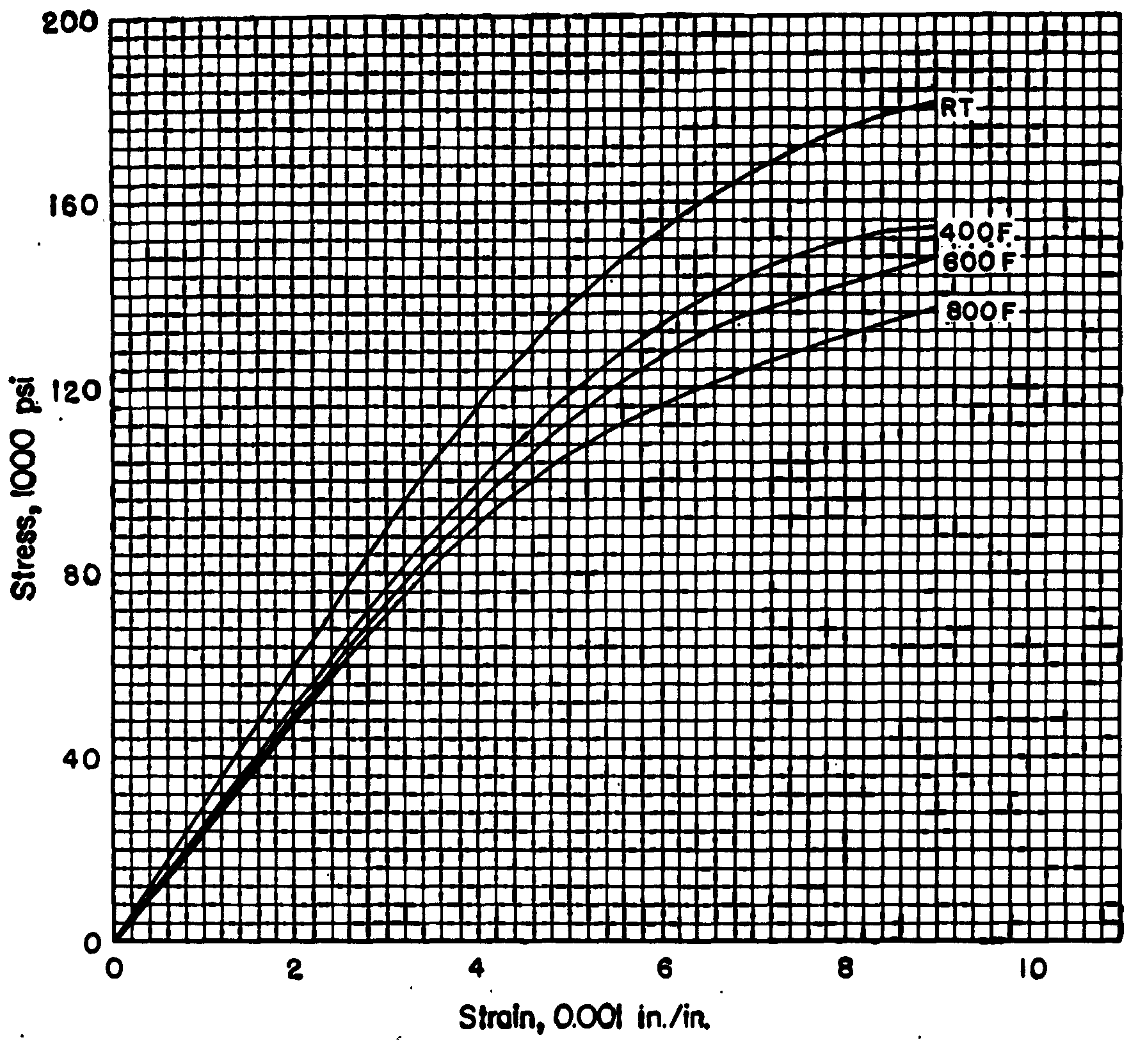

Figure 2.2.4.2.6(a). Typical tensile stress-strain curves for AM-350 stainless steel (SCT) at room and elevated temperatures.

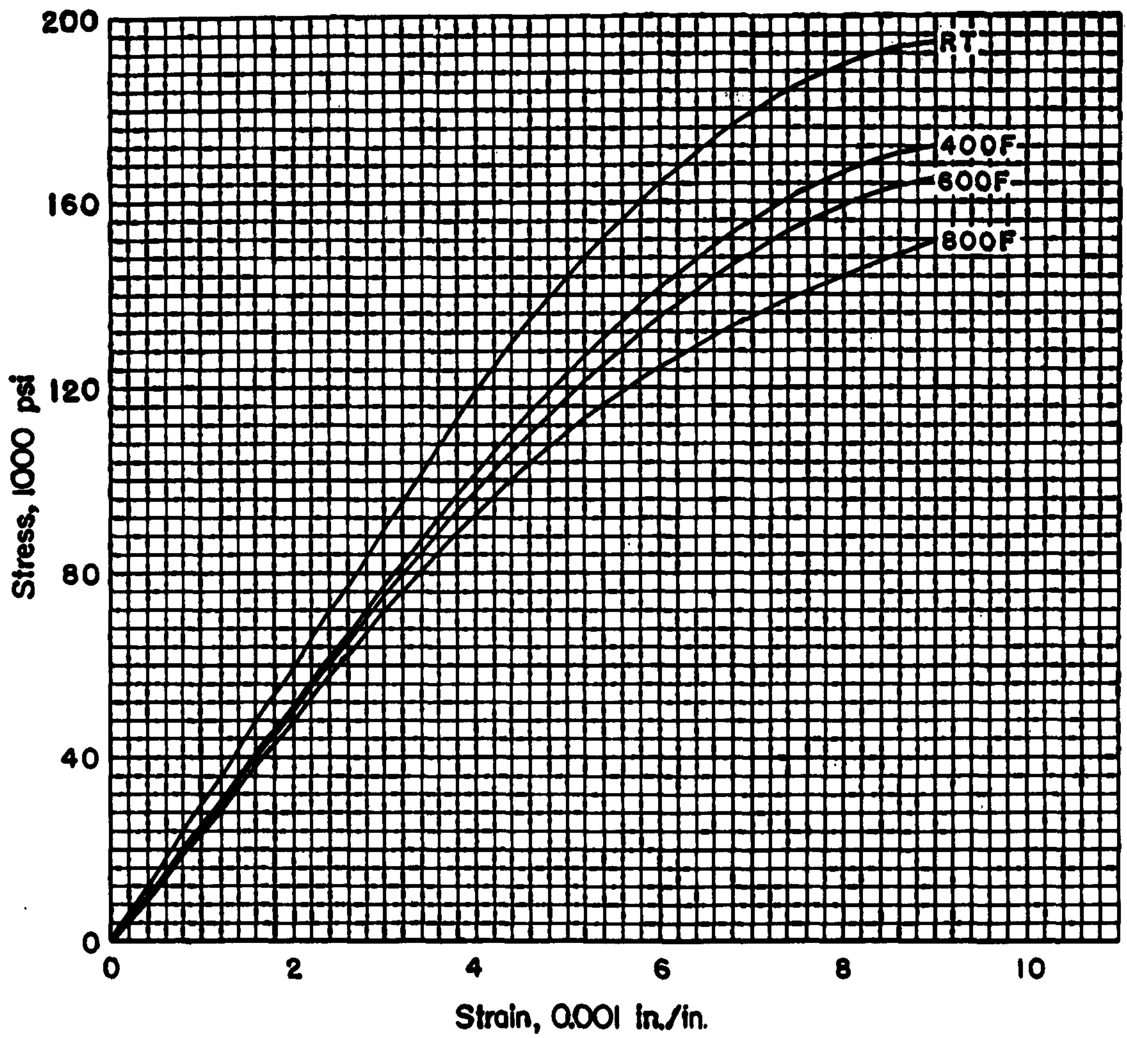

Figure 2.2.4.2.6(b). Typical compressive stress-strain curves for AM-350 stainless steel (SCT) at room and elevated temperatures.

APPENDIX B

SUPPORTING DATA FOR ROOM-TEMPERATURE ALLOWABLES AND ELEVATED-TEMPERATURE DESIGN CURVES

SUPPORTING DATA FOR ROOM-TEMPERATURE MECHANICAL-PROPERTY DESIGN ALLOWABLES FOR AM-350 (DA)

Source	
AMS	$F_{tu} = 165$ ksi
	$F_{ty} = 135$ ksi

Compressive Yield

NACA TN 4074, 4075	CYS = 164 ksi (average of L and T tests)
	UTS = 182 ksi
	$F_{tu} = 165$ ksi (guaranteed minimum)
	$F_{cy} = \frac{CYS}{UTS} \times F_{tu} = \frac{164}{182} \times 165 = 149$ ksi
	Ratio of $\frac{F_{cy}}{F_{tu}} = \frac{149}{165} = 0.90$
Allegheny Ludlum	CYS = 174.5 ksi
	UTS = 195.5 ksi
	$F_{tu} = 165.0$ ksi (guaranteed minimum)
	$F_{cy} = \frac{CYS}{UTS} \times F_{tu} = \frac{174.5}{195.5} \times 165 = 147$ ksi
	Ratio of $\frac{F_{cy}}{F_{tu}} = \frac{147}{165} = 0.894$
Att. 60-14	Ratio of $\frac{F_{cy}}{F_{tu}} = \frac{148}{165} = 0.897$

Ultimate Shear

Allegheny Ludlum	USS = 122.2 ksi (average of 4 tests)
	UTS = 179.1 ksi

F_{tu} = 165 ksi (guaranteed minimum)

$F_{su} = \frac{USS}{UTS} \times F_{tu} = \frac{122.2}{179.1} \times 165 = 112.5$ ksi

Ratio of $\frac{F_{su}}{F_{tu}} = \frac{112.5}{165} = 0.685$

Att. 60-14 | Ratio of $\frac{F_{su}}{F_{tu}} = \frac{112}{165} = 0.68$

Ultimate Bearing (e/D = 1.5)

WADC TR 58-672 | BUS = 276.1 ksi (average of L and T tests, heat 25417)

UTS = 179.7 ksi (average of L and T tests, heat 25417)

F_{tu} = 165 ksi (guaranteed minimum)

$F_{bru} = \frac{BUS}{UTS} \times F_{tu} = \frac{276.1}{179.7} \times 165 = 254$ ksi

Ratio of $\frac{F_{bru}}{F_{tu}} = \frac{254}{165} = 1.54$

WADC TR 58-672 | BUS = 258.0 ksi (1 transverse test)

UTS = 159.9 ksi (does not meet spec.)

F_{tu} = 165 ksi (guaranteed minimum)

$F_{bru} = \frac{BUS}{UTS} \times F_{tu} = \frac{258}{159.9} \times 165 = 266$ ksi

Ratio of $\frac{F_{bru}}{F_{tu}} = \frac{266}{165} = 1.61$

Allegheny Ludlum | BUS = 285.5 ksi

UTS = 179.1 ksi

F_{tu} = 165 ksi (guaranteed minimum)

$F_{bru} = \frac{BUS}{UTS} \times F_{tu} = \frac{285.5}{179.1} \times 165 = 262$ ksi

Ratio of $\frac{F_{bru}}{F_{tu}} = \frac{262}{165} = 1.59$

Att. 60-14 Ratio of $\frac{F_{bru}}{F_{tu}} = \frac{260}{165} = 1.575$

<u>Ultimate Bearing (e/D = 2.0)</u>

WADC TR 58-672

BUS = 362.5 ksi (average of L and T test)

UTS = 179.7 ksi (average of L and T test)

F_{tu} = 165 ksi (guaranteed minimum)

$$F_{bru} = \frac{BUS}{UTS} \times F_{tu} = \frac{362.5}{179.7} \times 165 = 333 \text{ ksi}$$

Ratio of $\frac{F_{bru}}{F_{tu}} = \frac{333}{165} = 2.02$

WADC TR 58-672

BUS = 344.0 ksi (average of L and T tests)

UTS = 159.9 ksi (does not meet spec.)

F_{tu} = 165 ksi (guaranteed minimum)

$$F_{bru} = \frac{BUS}{UTS} \times F_{tu} = \frac{344}{159.9} \times 165 = 355 \text{ ksi}$$

Ratio of $\frac{F_{bru}}{F_{tu}} = \frac{355}{165} = 2.15$

Att. 60-14 Ratio of $\frac{F_{bru}}{F_{tu}} = \frac{345}{165} = 2.09$

<u>Bearing Yield (e/D = 1.5)</u>

WADC TR 58-672

BYS = 212.7 ksi (average of L and T tests)

UTS = 179.7 ksi (average of L and T tests)

F_{tu} = 165 ksi (guaranteed minimum)

$$F_{bry} = \frac{BYS}{UTS} \times F_{tu} = \frac{212.7}{179.7} \times 165 = 196 \text{ ksi}$$

Ratio of $\frac{F_{bry}}{F_{tu}} = \frac{196}{165} = 1.19$

WADC TR 58-672

BYS = 197.2 ksi

UTS = 159.9 ksi (does not meet spec.)

F_{tu} = 165 ksi (guaranteed minimum)

$$F_{bry} = \frac{BYS}{UTS} \times F_{tu} = \frac{197.2}{159.9} \times 165 = 203 \text{ ksi}$$

$$\text{Ratio of } \frac{F_{bry}}{F_{tu}} = \frac{203}{165} = 1.23$$

Allegheny Ludlum

BYS = 215.8 ksi

UTS = 179.1 ksi

F_{tu} = 165 ksi (guaranteed minimum)

$$F_{bry} = \frac{BYS}{UTS} \times F_{tu} = \frac{215.8}{179.1} \times 165 = 198 \text{ ksi}$$

$$\text{Ratio of } \frac{F_{bry}}{F_{tu}} = \frac{198}{165} = 1.20$$

Att. 60-14

$$\text{Ratio of } \frac{F_{bry}}{F_{tu}} = \frac{198}{165} = 1.20$$

Bearing Yield (e/D = 2.0)

WADC TR 58-672

BYS = 252.0 ksi (average of L and T tests)

UTS = 179.7 ksi (average of L and T tests)

F_{tu} = 165 ksi (guaranteed minimum)

$$F_{bry} = \frac{BYS}{UTS} \times F_{tu} = \frac{252.0}{179.7} \times 165 = 231 \text{ ksi}$$

$$\text{Ratio of } \frac{F_{bry}}{F_{tu}} = \frac{231}{165} = 1.40$$

WADC TR 58-672

BYS = 222.7 ksi (average of L and T tests)

UTS = 159.9 ksi (does not meet spec.)

F_{tu} = 165 ksi (guaranteed minimum)

$$F_{bry} = \frac{BYS}{UTS} \times F_{tu} = \frac{222.7}{159.9} \times 165 = 230 \text{ ksi}$$

Ratio of $\frac{F_{bry}}{F_{tu}} = \frac{230}{165} = 1.395$

Att. 60-14 Ratio of $\frac{F_{bry}}{F_{tu}} = \frac{230}{165} = 1.395$

SUPPORTING DATA FOR ROOM-TEMPERATURE MECHANICAL-PROPERTY DESIGN ALLOWABLES FOR AM-350 (SCT)

Source

AMS F_{tu} = 185 ksi

F_{ty} = 150 ksi

Compressive Yield

Allegheny Ludlum CYS = 193.6 ksi (average of 3 heats)

UTS = 208.4 ksi (average of 3 heats)

F_{tu} = 185 ksi (guaranteed minimum)

$$F_{cy} = \frac{CYS}{UTS} \times F_{tu} = \frac{193.6}{208.4} \times 185 = 171.5 \text{ ksi}$$

Ratio of $\frac{F_{cy}}{F_{tu}} = \frac{171.5}{185} = 0.93$

NAA, MPDS Ratio of $\frac{F_{cy}}{F_{tu}} = \frac{164}{185} = 0.89$

Att. 60-14 Ratio of $\frac{F_{cy}}{F_{tu}} = \frac{170}{185} = 0.92$

Ultimate Shear

Allegheny Ludlum

USS = 137.7 ksi

UTS = 208.3 ksi

F_{tu} = 185 ksi (guaranteed minimum)

$$F_{su} = \frac{USS}{UTS} \times F_{tu} = \frac{137.7}{208.3} \times 185 = 122 \text{ ksi}$$

$$\text{Ratio of } \frac{F_{su}}{F_{tu}} = \frac{122}{185} = 0.66$$

NAA
(BTL 30468)

USS = 140 ksi

UTS = 210 ksi

F_{tu} = 185 ksi (guaranteed minimum)

$$F_{su} = \frac{USS}{UTS} \times F_{tu} = \frac{140}{210} \times 185 = 123.5 \text{ ksi}$$

$$\text{Ratio of } \frac{F_{su}}{F_{tu}} = \frac{123.5}{185} = 0.67$$

Att. 60-14

$$\text{Ratio of } \frac{F_{su}}{F_{tu}} = \frac{123}{185} = 0.665$$

Ultimate Bearing (e/D = 1.5)

WADC TR 58-672

BUS = 304.7 ksi (average of L and T tests, 2 heats)

UTS = 193.4 ksi (average of L and T tests, 2 heats)

F_{tu} = 185 ksi (guaranteed minimum)

$$F_{bru} = \frac{BUS}{UTS} \times F_{tu} = \frac{304.7}{193.4} \times 185 = 292 \text{ ksi}$$

$$\text{Ratio of } \frac{F_{bru}}{F_{tu}} = \frac{292}{185} = 1.58$$

Allegheny Ludlum

BUS = 348.9 ksi

UTS = 208.3 ksi

F_{tu} = 185 ksi (guaranteed minimum)

$$F_{bru} = \frac{BUS}{UTS} \times F_{tu} = \frac{348.9}{208.3} \times 185 = 310 \text{ ksi}$$

$$\text{Ratio of } \frac{F_{bru}}{F_{tu}} = \frac{310}{185} = 1.67$$

Att. 60-14

$$\text{Ratio of } \frac{F_{bru}}{F_{tu}} = \frac{295}{185} = 1.59$$

<u>Ultimate Bearing (e/D = 2.0)</u>

NAA (BTL 30468)

BUS = 410 ksi

UTS = 210 ksi

F_{tu} = 185 ksi (guaranteed minimum)

$$F_{bru} = \frac{BUS}{UTS} \times F_{tu} = \frac{410}{210} \times 185 = 361 \text{ ksi}$$

$$\text{Ratio of } \frac{F_{bru}}{F_{tu}} = \frac{361}{185} = 1.95$$

NAA (MPDS)

$$\text{Ratio of } \frac{F_{bru}}{F_{tu}} = \frac{380}{185} = 2.05$$

WADC TR 58-672

BUS = 392.1 ksi (average of L and T tests, 2 heats)

UTS = 193.4 ksi (average of L and T tests, 2 heats)

F_{tu} = 185 ksi (guaranteed minimum)

$$F_{bru} = \frac{BUS}{UTS} \times F_{tu} = \frac{392.1}{193.4} \times 185 = 375$$

$$\text{Ratio of } \frac{F_{bru}}{F_{tu}} = \frac{375}{185} = 2.02$$

Att. 60-14

$$\text{Ratio of } \frac{F_{bru}}{F_{tu}} = \frac{372}{185} = 2.01$$

Bearing Yield (e/D = 1.5)

WADC TR 58-672

BYS = 237.2 ksi (average of L and T tests, 2 heats)

UTS = 193.4 ksi (average of L and T tests, 2 heats)

F_{tu} = 185 ksi (guaranteed minimum)

$$F_{bry} = \frac{BYS}{UTS} \times F_{tu} = \frac{237.2}{193.4} \times 185 = 227 \text{ ksi}$$

$$\text{Ratio of } \frac{F_{bry}}{F_{tu}} = \frac{227}{185} = 1.23$$

Allegheny Ludlum

BYS = 272.0 ksi

UTS = 208.5 ksi

F_{tu} = 185 ksi (guaranteed minimum)

$$F_{bry} = \frac{BYS}{UTS} \times F_{tu} = \frac{272}{208.5} \times 185 = 241 \text{ ksi}$$

$$\text{Ratio of } \frac{F_{bry}}{F_{tu}} = \frac{241}{185} = 1.30$$

Att. 60-14

$$\text{Ratio of } \frac{F_{bry}}{F_{tu}} = \frac{230}{185} = 1.24$$

Bearing Yield (e/D = 2.0)

WADC TR 58-672

BYS = 227.6 ksi (average of L and T tests, 2 heats)

UTS = 193.4 ksi (average of L and T tests, 2 heats)

F_{tu} = 185 ksi (guaranteed minimum)

$$F_{bry} = \frac{BYS}{UTS} \times F_{tu} = \frac{277.6}{193.4} \times 185 = 265 \text{ ksi}$$

$$\text{Ratio of } \frac{F_{bry}}{F_{tu}} = \frac{265}{185} = 1.43$$

NAA (BTL 30468)	BYS = 290 ksi
	UTS = 210 ksi
	F_{tu} = 185 ksi (guaranteed minimum)
	$F_{bry} = \frac{BYS}{UTS} \times F_{tu} = \frac{290}{210} \times 185 = 256$ ksi
	Ratio of $\frac{F_{bry}}{F_{tu}} = \frac{256}{185} = 1.38$
NAA (MPDS)	Ratio of $\frac{F_{bry}}{F_{tu}} = \frac{256}{185} = 1.38$
Att. 60-14	Ratio of $\frac{F_{bry}}{F_{tu}} = \frac{260}{185} = 1.40$

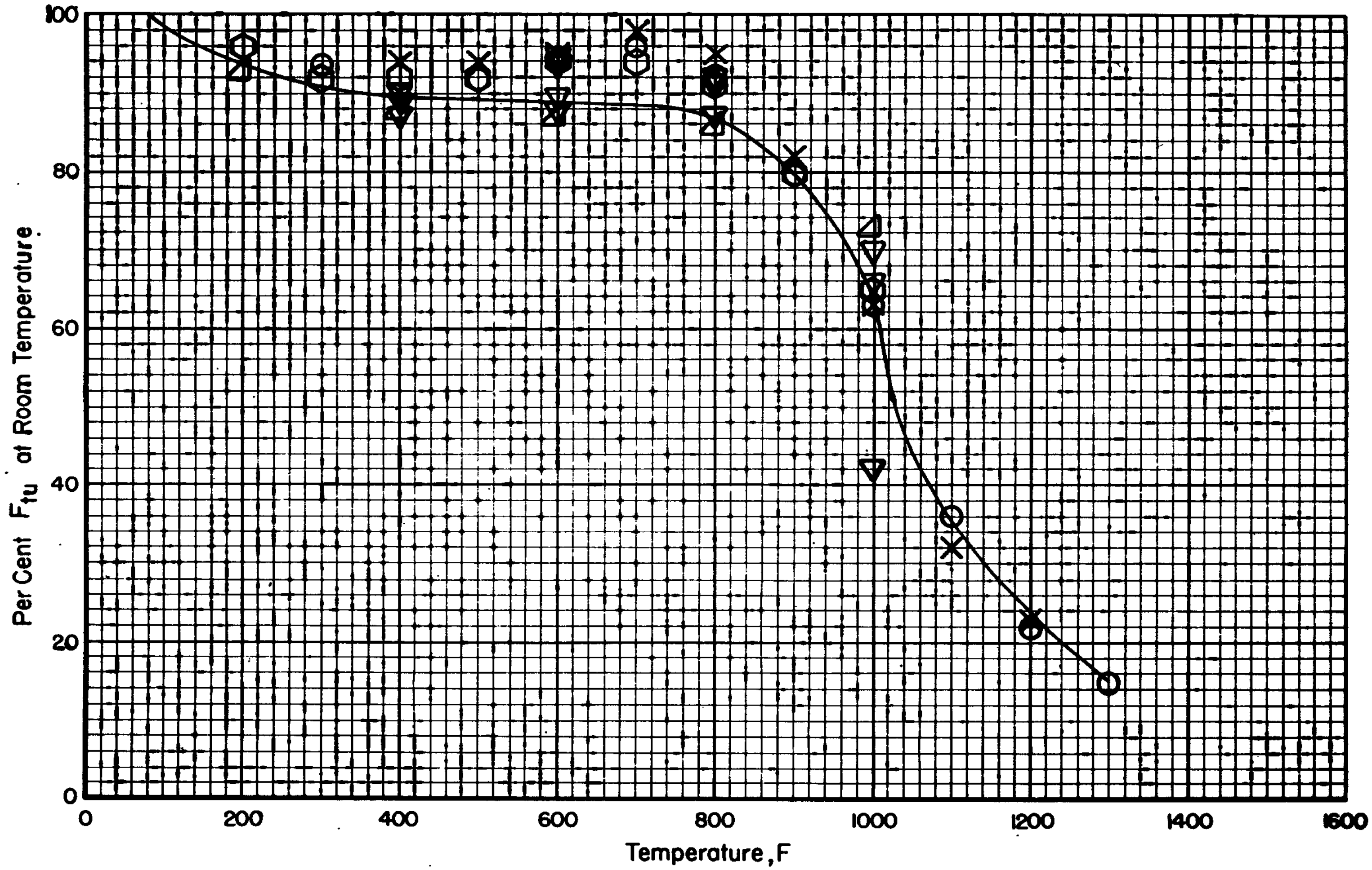

FIGURE 1. EFFECT OF TEMPERATURE ON THE ULTIMATE TENSILE STRENGTH (F_{tu}) OF AM-350 STAINLESS STEEL (DOUBLE AGED)

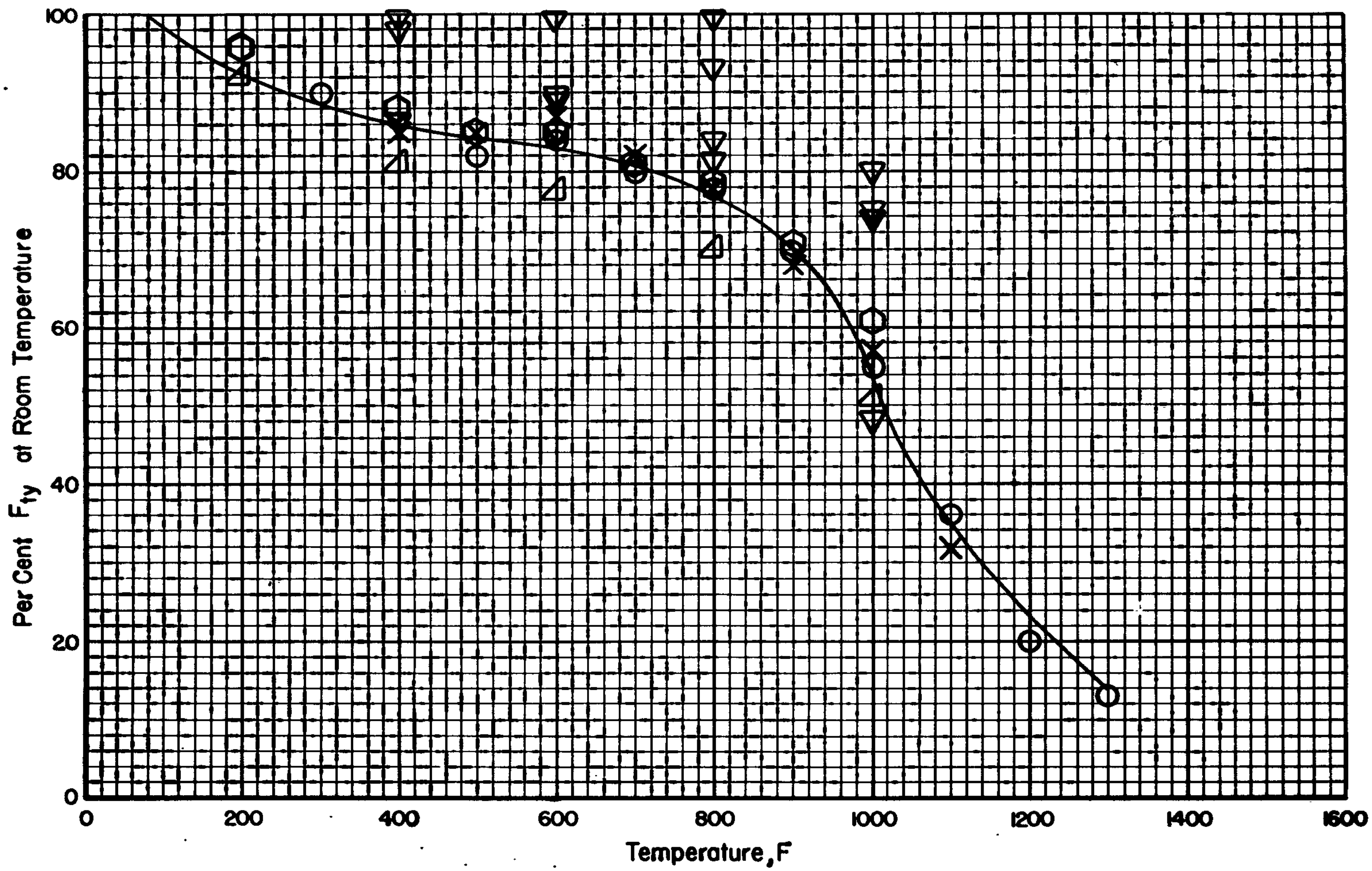

FIGURE 2. EFFECT OF TEMPERATURE ON THE TENSILE YIELD STRENGTH (F_{ty}) OF AM-350 STAINLESS STEEL (DOUBLE AGED)

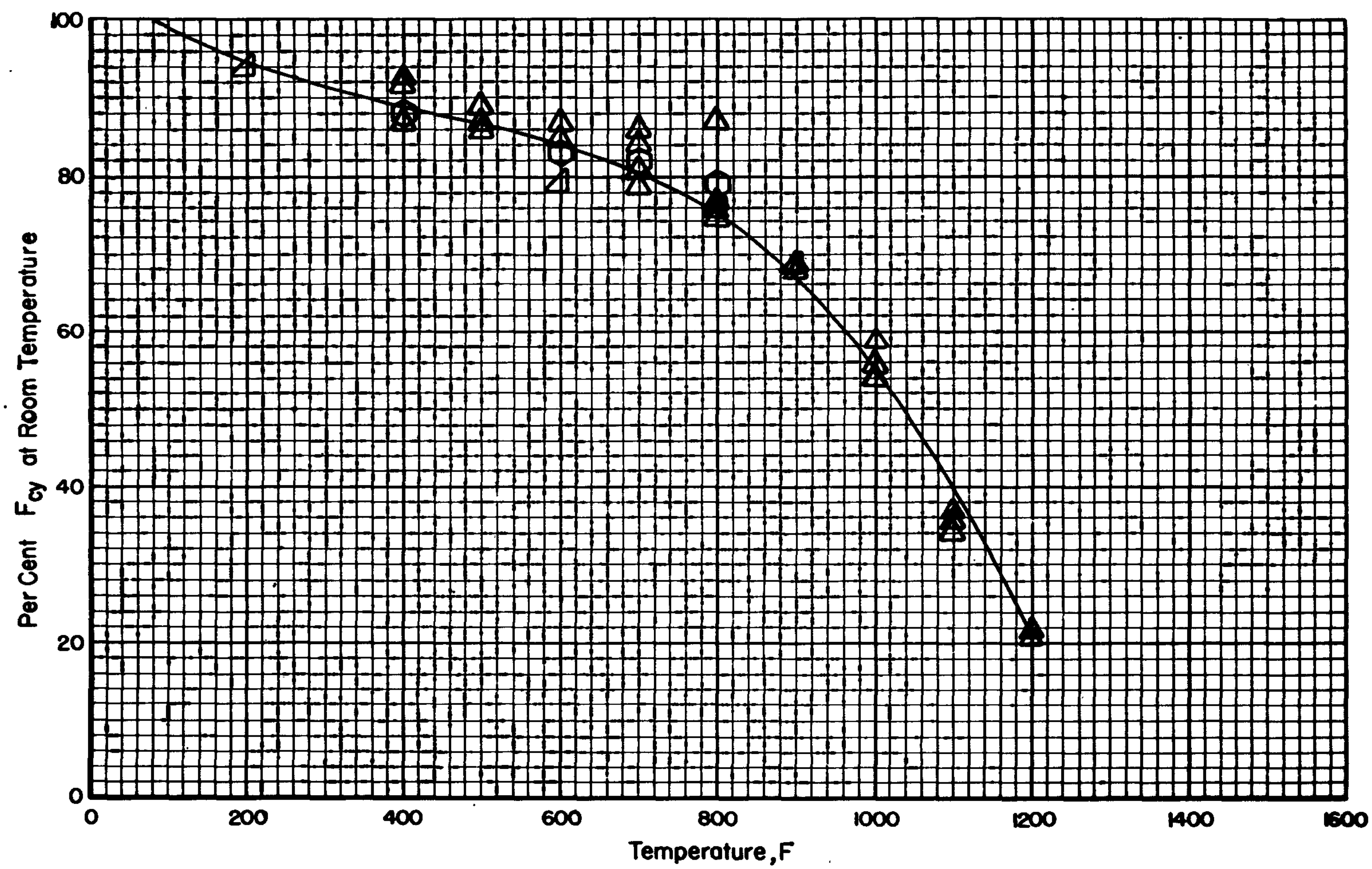

FIGURE 3. EFFECT OF TEMPERATURE ON THE COMPRESSIVE YIELD STRENGTH (F_{cy}) OF AM-350 STAINLESS STEEL (DOUBLE AGED)

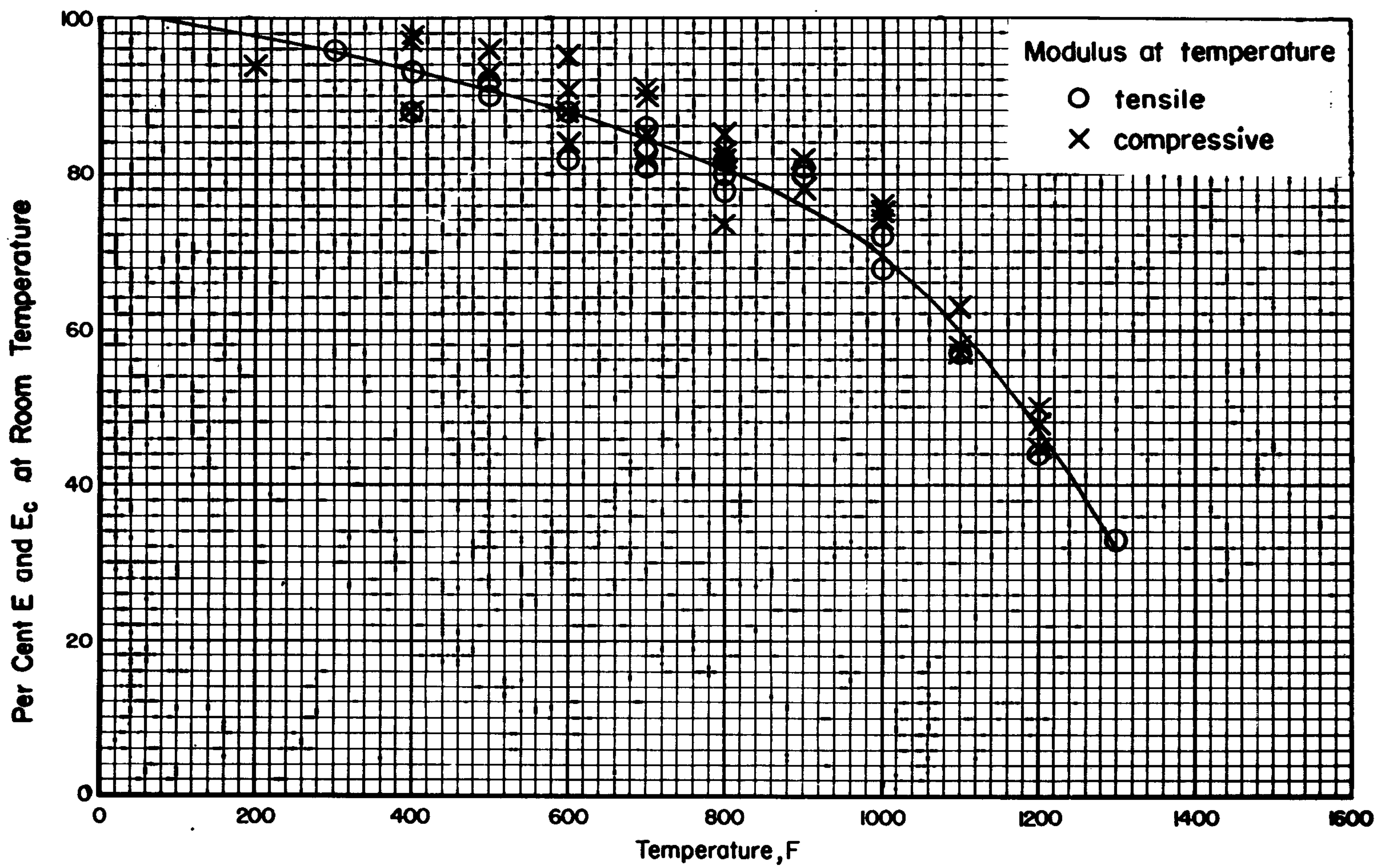

FIGURE 4. EFFECT OF TEMPERATURE ON THE TENSILE AND COMPRESSIVE MODULUS (E AND E_c) OF AM-350 STAINLESS STEEL (DOUBLE AGED)

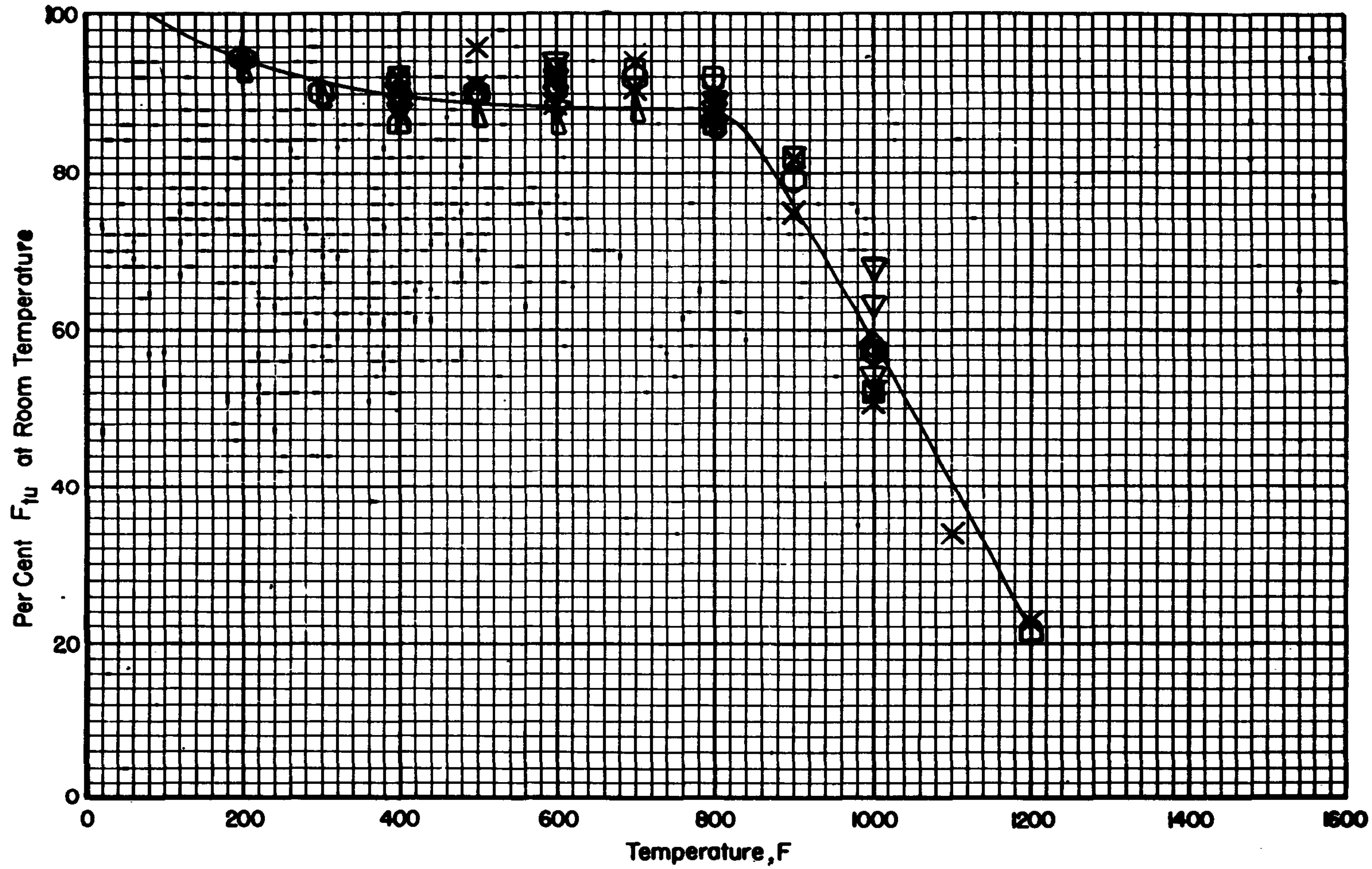

FIGURE 5. EFFECT OF TEMPERATURE ON THE ULTIMATE TENSILE STRENGTH (F_{tu}) OF AM-350 STAINLESS STEEL (SCT)

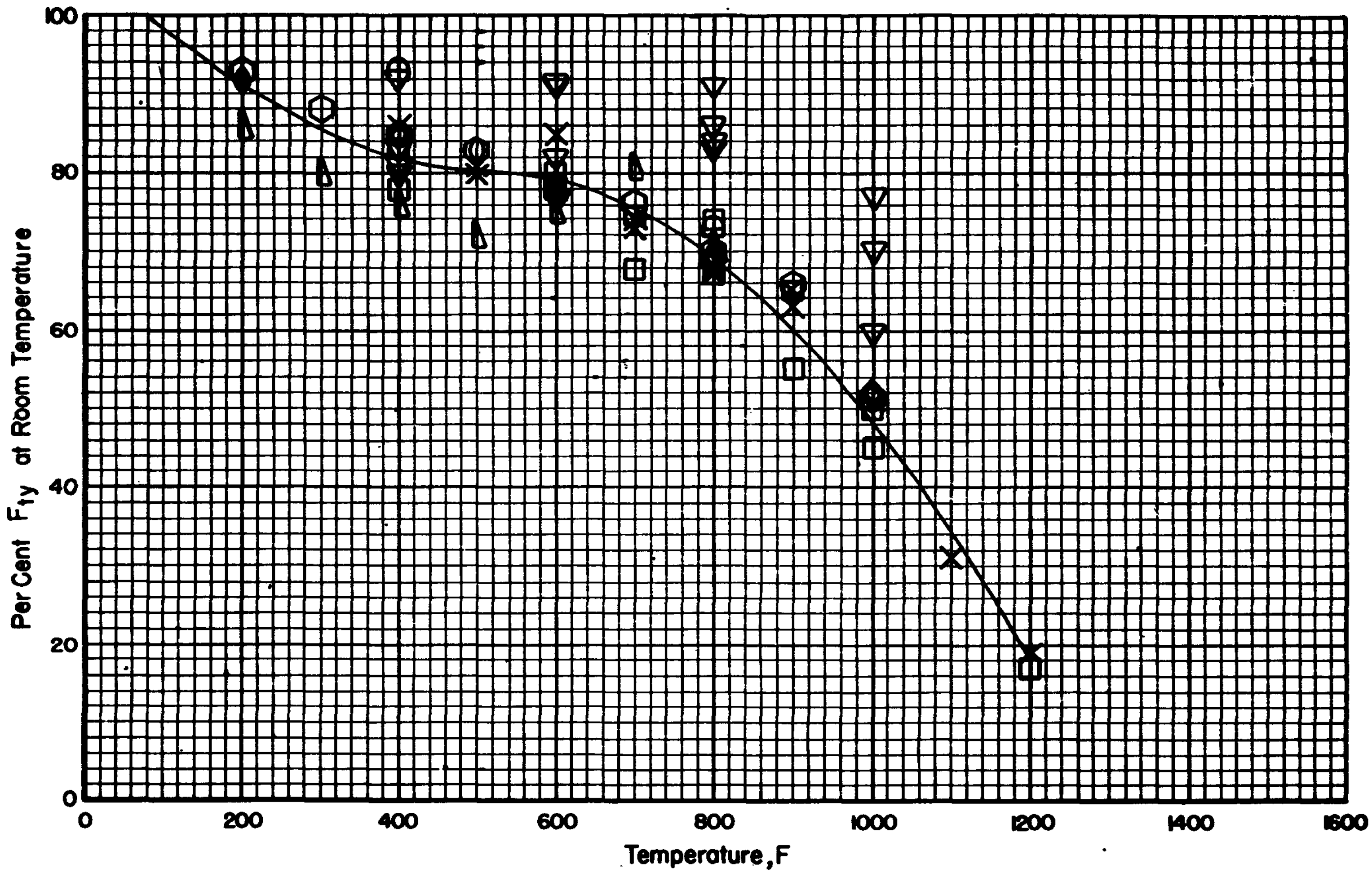

FIGURE 6. EFFECT OF TEMPERATURE ON THE TENSILE YIELD STRENGTH (F_{ty}) OF AM-350 STAINLESS STEEL (SCT)

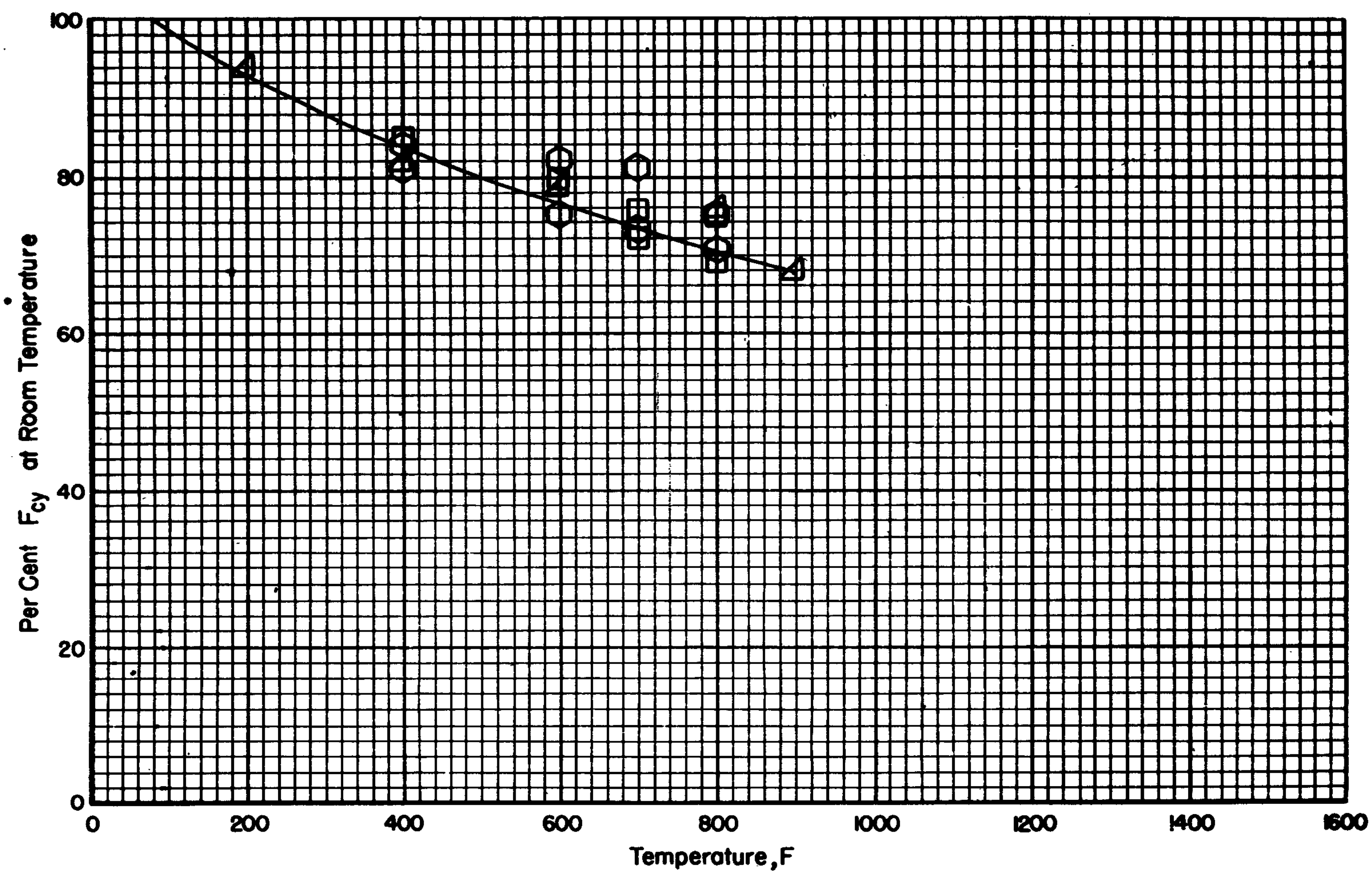

FIGURE 7. EFFECT OF TEMPERATURE ON THE COMPRESSIVE YIELD STRENGTH (F_{cy}) OF AM-350 STAINLESS STEEL (SCT)

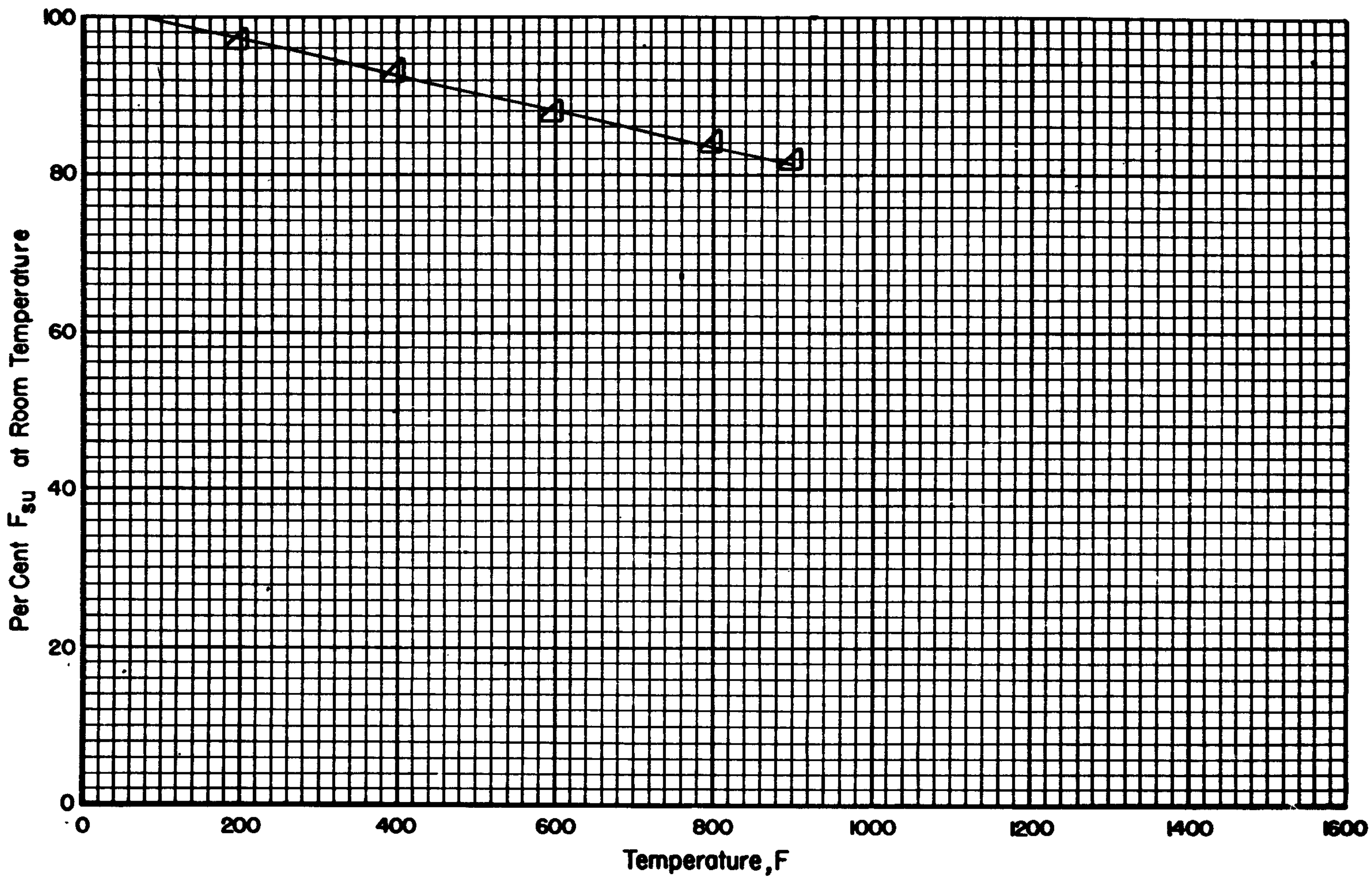

FIGURE 8. EFFECT OF TEMPERATURE ON THE ULTIMATE SHEAR STRENGTH (F_{su}) OF AM-350 STAINLESS STEEL (SCT)

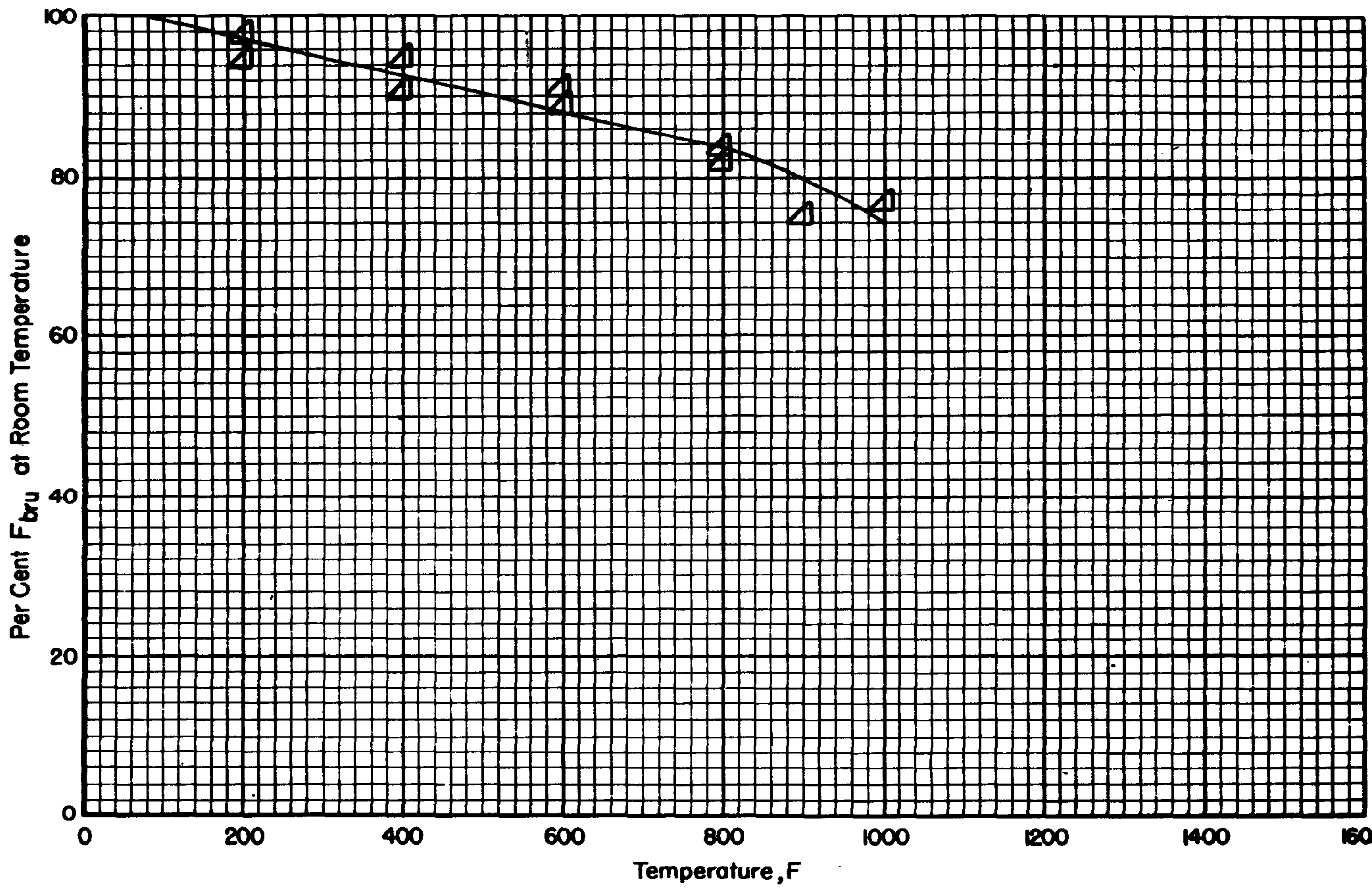

FIGURE 9. EFFECT OF TEMPERATURE ON THE ULTIMATE BEARING STRENGTH (F_{bru}) OF AM-350 STAINLESS STEEL (SCT)

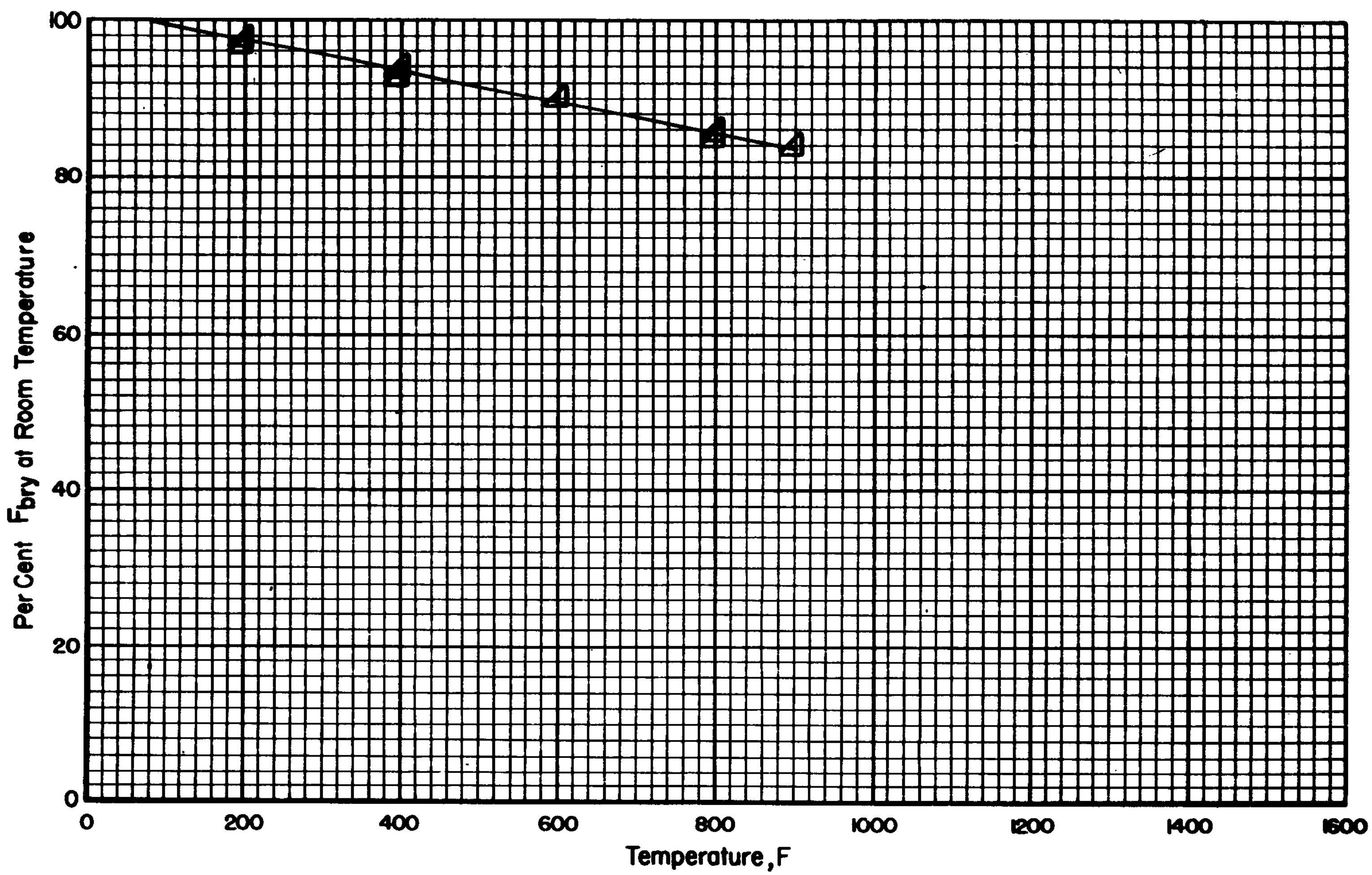

FIGURE 10. EFFECT OF TEMPERATURE ON THE BEARING YIELD STRENGTH (F_{bry}) OF AM-350 STAINLESS STEEL (SCT)

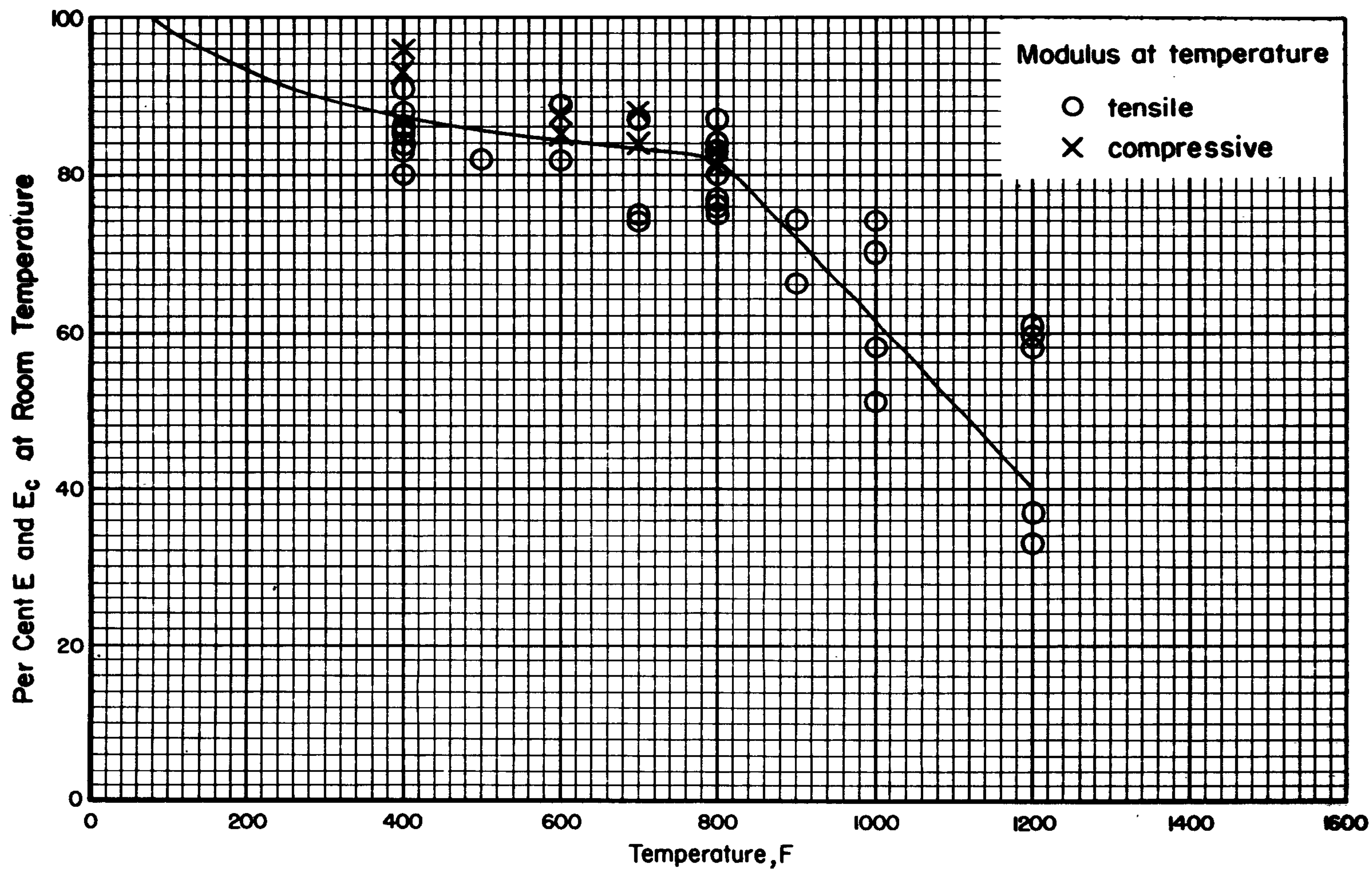

FIGURE 11. EFFECT OF TEMPERATURE ON THE TENSILE AND COMPRESSIVE MODULUS (E AND E_c) OF AM-350 STAINLESS STEEL (SCT)

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46E	Department of Defense Titanium Sheet-Rolling Program - Thermal Stability of the Titanium Sheet-Rolling-Program Alloys, November 25, 1958 (PB 151061 $1.25)
46F	Department of Defense Titanium Sheet-Rolling Program Status Report No. 4, March 20, 1959 (PB 151065 $2.25)
46G	Department of Defense Titanium Sheet-Rolling Program - Time-Temperature-Transformation Diagrams of the Titanium Sheet-Rolling Program Alloys, October 19, 1959 (PB 151075 $2.25)
46H	Department of Defense Titanium Sheet-Rolling Program, Status Report No. 5, June 1, 1960 (PB 151087 $2.00)
46I	Statistical Analysis of Tensile Properties of Heat-Treated Ti-4Al-3Mo-1V Sheet, September 16, 1960 (PB 151095 $1.25)
106	Beryllium for Structural Applications, August 15, 1958 (PB 121648 $3.00)
107	Tensile Properties of Titanium Alloys at Low Temperature, January 15, 1959 (PB 151062 $1.25)
108	Welding and Brazing of Molybdenum, March 1, 1959 (PB 151063 $1.25)
109	Coatings for Protecting Molybdenum From Oxidation at Elevated Temperature, March 6, 1959 (PB 151064 $1.25)
110	The All-Beta Titanium Alloy (Ti-13V-11Cr-3Al), April 17, 1959 (PB 151066 $3.00)
111	The Physical Metallurgy of Precipitation-Hardenable Stainless Steels, April 20, 1959 (PB 151067 $2.00)
112	Physical and Mechanical Properties of Nine Commercial Precipitation-Hardenable Stainless Steels, May 1, 1959 (PB 151068 $3.25)
113	Properties of Certain Cold-Rolled Austenitic Stainless Sheet Steels, May 15, 1959 (PB 151069 $1.75)
114	Ductile-Brittle Transition in the Refractory Metals, June 25, 1959 (PB 151070 $2.00)
115	The Fabrication of Tungsten, August 14, 1959 (PB 151071 $1.75)
116R	Design Information on 5Cr-Mo-V Alloy Steels (H-11 and 5Cr-Mo-V Aircraft Steel) for Aircraft and Missiles (Revised), September 30, 1960 (PB 151072-R $1.50)
117	Titanium Alloys for High-Temperature Use Strengthened by Fibers or Dispersed Particles, August 31, 1959 (PB 151073 $2.00)
118	Welding of High-Strength Steels for Aircraft and Missile Applications, October 12, 1959 (PB 151074 $2.25)
119	Heat Treatment of High-Strength Steels for Aircraft Applications, November 27, 1959 (PB 151076 $2.50)
120	A Review of Certain Ferrous Castings Applications in Aircraft and Missiles, December 18, 1959 (PB 151077 $1.50)
121	Methods for Conducting Short-Time Tensile, Creep, and Creep-Rupture Tests Under Conditions of Rapid Heating, December 20, 1959 (PB 151078 $1.25)
122	The Welding of Titanium and Titanium Alloys, December 31, 1959 (PB 151079 $1.75)
123	Oxidation Behavior and Protective Coatings for Columbium and Columbium-Base Alloys, January 15, 1960 (PB 151080 $2.25)
124	Current Tests for Evaluating Fracture Toughness of Sheet Metals at High Strength Levels, January 28, 1960 (PB 151081 $2.00)
125	Physical and Mechanical Properties of Columbium and Columbium-Base Alloys, February 22, 1960 (PB 151082 $1.75)
126	Structural Damage in Thermally Cycled René 41 and Astroloy Sheet Materials, February 29, 1960 (PB 151083 $0.75)
127	Physical and Mechanical Properties of Tungsten and Tungsten-Base Alloys, March 15, 1960 (PB 151084 $1.75)
128	A Summary of Comparative Properties of Air-Melted and Vacuum-Melted Steels and Superalloys, March 28, 1960 (PB 151085 $2.75)
129	Physical Properties of Some Nickel-Base Alloys, May 20, 1960 (PB 151086 $2.75)
130	Selected Short-Time Tensile and Creep Data Obtained Under Conditions of Rapid Heating, June 17, 1960 (PB 151088 $2.25)
131	New Developments in the Welding of Metals, June 24, 1960 (PB 151089 $1.25)
132	Design Information on Nickel-Base Alloys for Aircraft and Missiles, July 20, 1960 (PB 151090 $3.00)
133	Tantalum and Tantalum Alloys, July 25, 1960 (PB 151091 $5.00)
134	Strain Aging of Refractory Metals, August 12, 1960 (PB 151092 $1.75)
135	Design Information on PH 15-7 Mo Stainless Steel for Aircraft and Missiles, August 22, 1960 (PB 151093 $1.25)

DMIC Report Number	Title
136A	The Effects of Alloying Elements in Titanium, Volume A. Constitution, September 15, 1960(PB 151094 $3.50)
136B	The Effects of Alloying Elements in Titanium, Volume B. Physical and Chemical Properties, Deformation and Transformation Characteristics, May 29, 1961
137	Design Information on 17-7 PH Stainless Steels for Aircraft and Missiles, September 23, 1960(PB 151096 $1.00)
138	Availability and Mechanical Properties of High-Strength Steel Extrusions, October 26, 1960(PB 151097 $1.75)
139	Melting and Casting of the Refractory Metals Molybdenum, Columbium, Tantalum, and Tungsten, November 18, 1960 (PB 151098 $1.00)
140	Physical and Mechanical Properties of Commercial Molybdenum-Base Alloys, November 30, 1960(PB 151099 $3.00)
141	Titanium-Alloy Forgings, December 19, 1960 (PB 151100 $2.25)
142	Environmental Factors Influencing Metals Applications in Space Vehicles, December 27, 1960(PB151101$1.25)
143	High-Strength-Steel Forgings, January 5, 1961 (PB 151102 $1.75)
144	Stress-Corrosion Cracking – A Nontechnical Introduction to the Problem, January 6, 1961 (PB 151103 $0.75)
145	Design Information on Titanium Alloys for Aircraft and Missiles, January 10, 1961
146	Manual for Beryllium Prospectors, January 18, 1961 (PB 151105 $1.00)
147	The Factors Influencing the Fracture Characteristics of High-Strength Steel, February 6, 1961(PB 151106 $1.25)
148	Review of Current Data on the Tensile Properties of Metals at Very Low Temperatures, February 14, 1961 (PB 151107 $2.00)
149	Brazing for High Temperature Service, February 21, 1961 (PB 151108 $1.00)
150	A Review of Bending Methods for Stainless Steel Tubing, March 2, 1961 (PB 151109 $1.50)
151	Environmental and Metallurgical Factors of Stress-Corrosion Cracking in High-Strength Steels, April 14, 1961
152	Binary and Ternary Phase Diagrams of Columbium, Molybdenum, Tantalum, and Tungsten, April 28, 1961
153	Physical Metallurgy of Nickel-Base Superalloys, May 5, 1961
154	Evolution of Ultrahigh-Strength, Hardenable Steels for Solid-Propellant Rocket-Motor Cases, May 25, 1961
155	Oxidation of Tungsten, July 17, 1961.

Battelle Memorial Institute, Defense Metals Information Center, Columbus, Ohio. DESIGN INFORMATION ON AM-350 STAINLESS STEEL FOR AIRCRAFT AND MISSILES, by R. J. Favor, O. L. Deel, and W. P. Achbach. July 27, 1961. 46 pp incl. illus., tables (DMIC Report 156) [AF 33(616)-7747] Unclassified Report

Tentative room-temperature design-allowable strengths and elevated-temperature design curves are presented for short-time ultimate tensile strength, tensile yield strength, compressive yield strength, ultimate shear strength, bearing ultimate strength, and bearing yield strength.

UNCLASSIFIED

1. Aircraft – Materials
2. Guided Missiles – Materials
3. Steel – Mechanical properties

I. Favor, R. J.
II. Deel, O. L.
III. Achbach, W. P.
IV. Defense Metals Information Center
V. Contract AF 33(616)-7747

UNCLASSIFIED

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1. Aircraft – Materials
2. Guided Missiles – Materials
3. Steel – Mechanical properties

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II. Deel, O. L.
III. Achbach, W. P.
IV. Defense Metals Information Center
V. Contract AF 33(616)-7747

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